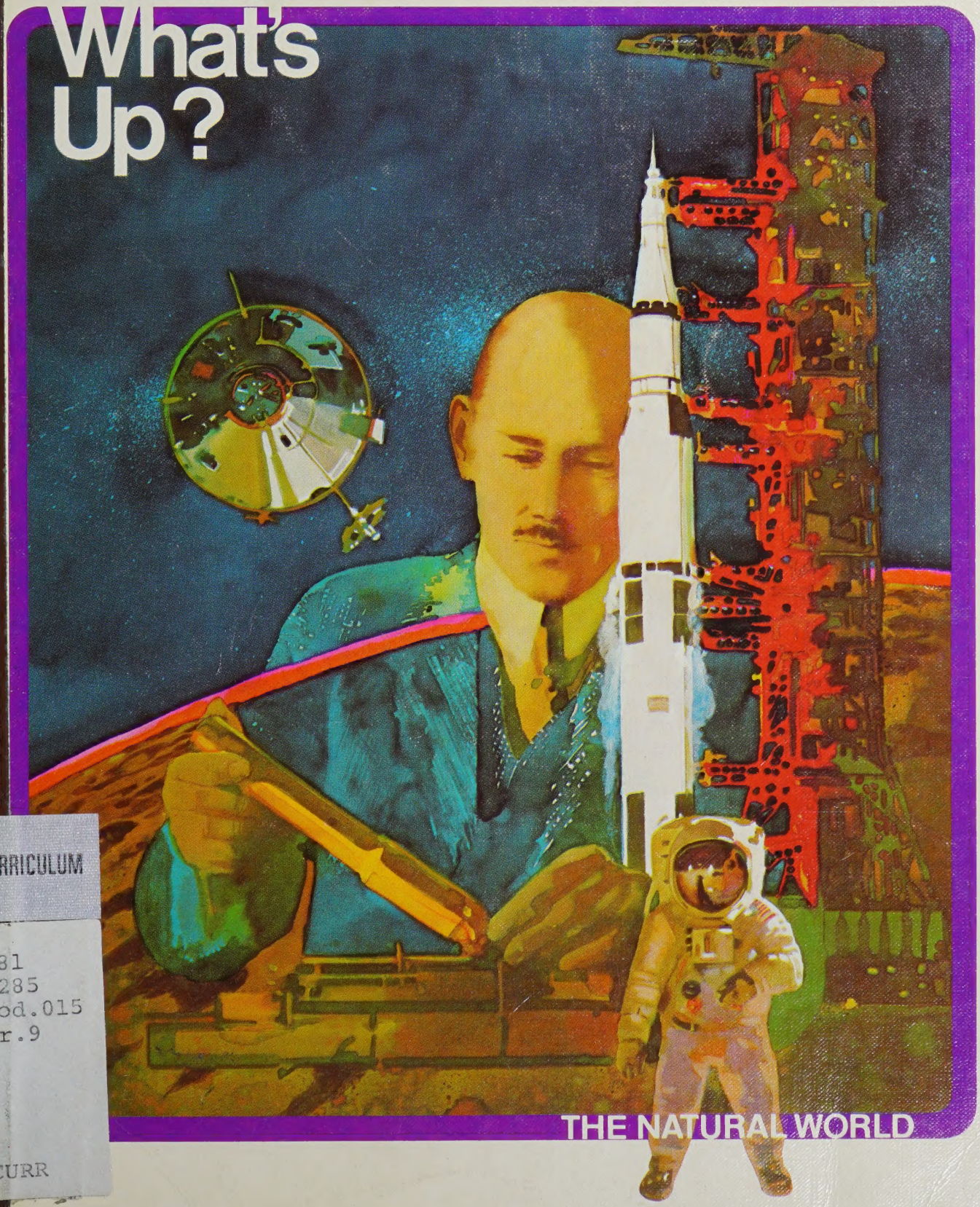
Teacher's Edition

What's Up?



THE NATURAL WORLD

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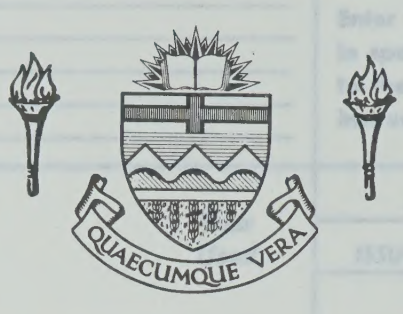

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2. The following terms should be used in recording the condition of the book: New; Good; Fair; Poor; Bad.

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Teacher's Edition

THE NATURAL WORLD MODULES/LEVEL 3

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Introduction

These modules are quite unlike most materials used in science courses. The content, the approach, and the underlying objectives probably stand in sharp contrast to those in the books you are accustomed to.

This Teacher's Edition has been designed to help you help your students as they study this module. Parts A and B give a brief overview of the module and its objectives. Parts C and D provide some detailed information about equipment, local supply items, and safety. Marginal notes in the chapters identify key questions, alert you to materials that must be prepared in advance, and suggest how to handle certain trouble spots. You may wish to add notes of your own as you work with this module.

The authors suggest that you read "A Brief Talk," in the introductory section of the student portion of each module, before you begin using the modules in your teaching. And of course you'll want to make regular use of the Instructional Management Guide. It has all kinds of suggestions for making the best use of the modules, the Record Books, and the Resource Book.

PART A • OVERVIEW

This module divides rather naturally into two parts. The first part enables the students to study how to get a rocket off the pad, to a high altitude, into a desired orbit, or even on a path

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to the moon. The second part looks at conditions likely to be found on the moon. To help the students understand the lunar features, they are compared with similar features on the earth. Then the students examine the relative motions of the moon and the earth around the sun before the return trip home.

Chapter 1 introduces the students to plastic rockets which are used to measure rocket performance. Students construct quadrants to aid in finding the height attained by the rocket, and investigate the factors that affect this measure of performance.

Chapter 2 continues the investigation of rocketry by examining unbalanced forces. Students find that an unbalanced force tends to cause a body to move. The force resulting from material rushing out of an opening is dependent upon the mass of material expelled per second and the speed at which it is expelled. The force also decreases when the jet discharges into a denser medium.

Excursion 2-1 gives the student practice in measuring forces in standard units. Thus it is useful for those who have forgotten, or who have had little or no experience with, force measurement. Along the way, Newton's laws of inertia, acceleration, and reaction are stated.

Chapter 3 asks the question of how much force, or thrust, is needed to lift a rocket off the pad, accelerate it, and put it into orbit. Students find that the amount of force is dependent on both the mass of the object being moved and the rate at which the object is being accelerated. These findings are made by using a cart, masses, and a force measurer, rather than a rocket.

Excursion 3-1 examines how burning fuel in a rocket engine develops thrust. The matter model is used as the basis for the explanation of how fuels contain chemical energy, how they release this energy as their particles are rearranged, and why the gases produced expand to provide the rocket thrust.

Excursion 3-2 concentrates on Newton's law of action and reaction. It uses a cart that "reacts" to an object thrown from it by moving in the opposite direction. This reaction principle is then applied to the concept of stages in a large rocket used for space travel.

Chapter 4 lets students investigate the factors that influence a moving body near the surface of the earth (gravity and air resistance). On the basis of experimentation and reasoning, they find the speed necessary to orbit a body at a low altitude. Then they see how the factors change at higher altitudes. Finally, they study satellite orbits and see how to plan a trajectory toward the moon.

Excursion 4-1 uses the pendulum as a means of studying the factors that affect the rate of fall of a body. Students find that on the basis of pendulum swings, and neglecting air resistance, all bodies falling from an equal height fall at the same rate.

Excursion 4-2 traces the reasoning that Newton may have used to formulate the law of universal gravitation. It illustrates how a difficult problem may be solved by analyzing a simple system. For instance, the attraction of the earth to an apple, causing it to fall, gives a clue about the mutual attraction between the moon and the earth.

Excursion 4-3 describes a special kind of satellite that is used for worldwide communications. The excursion uses a graph to find the relationship between satellite height and period.

Excursion 4-4 shows how heat in large quantities can be dissipated from a body such as a spacecraft. The method is applied from the melting of a block of ice to the ablation of the nose cone of a space vehicle upon re-entry into the atmosphere.

Chapter 5 allows the students to experiment with the formation of craters in sand and bentonite. On the basis of their experimentation, and after examining earth craters, they develop a model for crater formation on the moon. One of the factors getting special attention is the relative age of various moon features.

Excursion 5-1 examines the effects of decreased gravity and lack of atmosphere on objects in motion on the moon. And if some of these objects escape lunar gravity, they may appear, and be collected, on the earth.

Chapter 6 continues with the examination of crater formation, as well as peaks, cones, and domes. Clues for the identi-

fication of meteor impact, volcanism, and uplift as the possible cause of features are listed for student use. A possible reason for modification of lunar features is also postulated.

Chapter 7 gives details of a landing on the moon, with attention paid to conditions that might be encountered. Then students use a physical model of the sun-earth-moon system to predict the length of a lunar day, the moon's appearance from the earth, and the earth's appearance from the moon.

Excursion 7-1 affords the opportunity to examine features on the far side of the moon. The examination shows that the same kinds of events have occurred over the entire surface of the moon.

PART B • MODULE OBJECTIVES

Chapter 1

- Identifies the one factor that best measures performance of a water rocket.
- Explains why variables must be controlled in measuring rocket height.
- Calculates the height of a rocket, given distance from launch, sighting angle, and the table.
- Explains the advantage of averaging several measurements instead of using a single measurement.
- Demonstrates the use of a quadrant, metrestick, and table.
- Names the two variables that control rocket performance.
- Identifies how the two variables that control rocket performance interact.
- Identifies what must be done in constructing a measuring instrument to make it usable.

Chapter 2

- Identifies the cause of motion of an object.
- Identifies the relationship between rocket thrust and mass of matter ejected per second.
- Identifies the relationship between speed of the matter ejected from a rocket and rocket thrust.
- Uses graphs to find the relationship between variables.

•Explains the effect of outside substances on rocket thrust.
•Recognizes what a force is, and how it can be measured.

Chapter 3

•Calculates the total weight of a rocket.
•Explains the relationship between upward thrust and downward force on rocket motion.
•Identifies water-drop patterns with varying speeds of a cart.
•Calculates average distance.
•Infers the relationship between water-drop pattern and unbalanced force.
•Describes the effect of an unbalanced force on rocket speed.
•Explains the effect of changing one variable at a time in a speed, mass, and force relationship.

Chapter 4

•Explains the factors that control the time for a body to fall some distance.
•Explains the relationship between horizontal speed and distance traveled of a falling body.
•Explains how drag force (air resistance) on a rocket varies with altitude and speed.
•Defines period of a satellite.
•Demonstrates the ability to draw a graph.
•Demonstrates the ability to read data from a graph.
•Calculates orbiting speed.
•Relates gravitational attraction to height of orbit.
•Relates speed to orbit shape of a satellite.
•Identifies the effect of air resistance on a satellite and its surroundings.

Chapter 5

•Relates the incident angle of light to perceived shapes of features.
•Names the two variables that affect the amount of energy of a moving object.
•Relates crater size to speed of impact.
•Relates crater size to mass of impacting object.
•Distinguishes between crater types.
•Infers relative age of craters.
•Distinguishes features by shadows cast.
•Uses modeling to explain features on the moon.

Chapter 6

- Uses dropping water to model central peak formation on the moon.
- Describes the characteristics that distinguish volcanic craters from impact craters.
- Uses modeling to explain the formation of features on the moon.
- Distinguishes between modification of features on the earth and on the moon.

Chapter 7

- Uses a model of the sun-earth-moon system.
- Identifies the terminator on a heavenly body.
- Explains the earth-moon system.
- Recalls the period of the earth around the sun.

PART C • SPECIAL EQUIPMENT AND MATERIALS

Advance Preparations

You will need to plan for the rocket launchings in Chapter 1. This includes the following.

1. Survey the area around your school to determine where students should be directed. See the teacher notes in Chapter 1 for suggestions.
2. Arrange with the school administration for students to be out of the classroom.
3. Plan to hold a briefing session with students to discuss safety procedures before they start using the rockets.
4. Decide the method that students might use to measure 25 metres by pacing and, if desired, set up a 10-metre range as suggested in the teacher notes.
5. Pre-grease or oil the pumps and delegate the responsibility for keeping them lubricated.

Have your students bring in baby-food jars to be used in Chapters 2, 3, and 6, and Excursion 5-1. Get clean sand for Chapters 5 and 6 early. It may need drying, as it must be clean and dry for the experiments.

Local Supply List

String
Cardboard
Scissors
Ruler
Pencil
Oil or grease
Baby-food jars
Watch or clock, with second hand
Paper clips
Paper towels
Tape
Rubber bands, large and small
Matches
Thread
Paper cup
Newspapers
Sand
Magnifier or microscope
Plastic wrap
Bar magnet
Spoon
Microscope slide
Extension cords for floodlights in Chapters 5, 6, and 7 if needed

PART D • SAFETY NOTES

The plastic rockets, although safe when properly used, need to be carefully introduced to your students. They are primarily amusement devices and may induce a careless attitude. They should never be pointed at people, buildings, or wires. Students should not lean over the rocket when it's pumped up.

In Excursion 3-2, a clay ball is ejected by the force-measurer blade. In Chapter 4 a ball is launched by the same instrument. Any time anything is thrown in a classroom, there is a potential danger. Students should be cautioned and, if necessary, carefully monitored in the activities.

Before beginning this module, it would be good to have your students view the filmstrip *Laboratory Safety,* developed by EdMediaTec and distributed by Silver Burdett.

NOTES

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Contents

A Brief Talk v

Chapter 1/Up, Up, and Away 1

Chapter 2/What a Reaction! 11
Excursion 2–1/Newtons of Force 23

Chapter 3/How Much Is Needed? 29
Excursion 3–1/The Big Push 40
Excursion 3–2/One Stage at a Time 43

Chapter 4/All Systems Are Go 51
Excursion 4–1/Time to Fall 70
Excursion 4–2/The Falling Apple 73
Excursion 4–3/Orbiting Syncom 76
Excursion 4–4/Losing Heat 79

Chapter 5/Creating Craters 83
Excursion 5–1/Less Force 106

Chapter 6/Peaks and Flows 109

Chapter 7/A Day on the Moon 121
Excursion 7–1/An Excursion to the Far Side 129

Index 133

A Brief Talk

There are many ways to study science. No single way is the best for everybody. We've prepared this book, and others, to introduce you to science a bit at a time. We could have written a long book with many ideas and many chapters. Instead, we chose to present a few important things for you to think about in each of these books. And we've done it in such a way that you can *do* science activities—not just read about them.

To do science activities, you need equipment and materials. So we have asked that these be gathered together right in your classroom. Look around; you'll probably see some of them.

Getting What You Want

Each book like this one has a purpose. The title will give you some idea of what's inside. But to get a better idea of what's there, thumb through the pages. See what activities you'll be doing and the kind of equipment you'll be using.

First, you'll have a say in choosing the modules you want to study. Second, you can choose to do, or not to do, some of the activities within each module. These activities are called Excursions. Third, you can get help with your own special problems by doing other short activities. These activities are called Resources. You'll find them in the *Resource Book*.

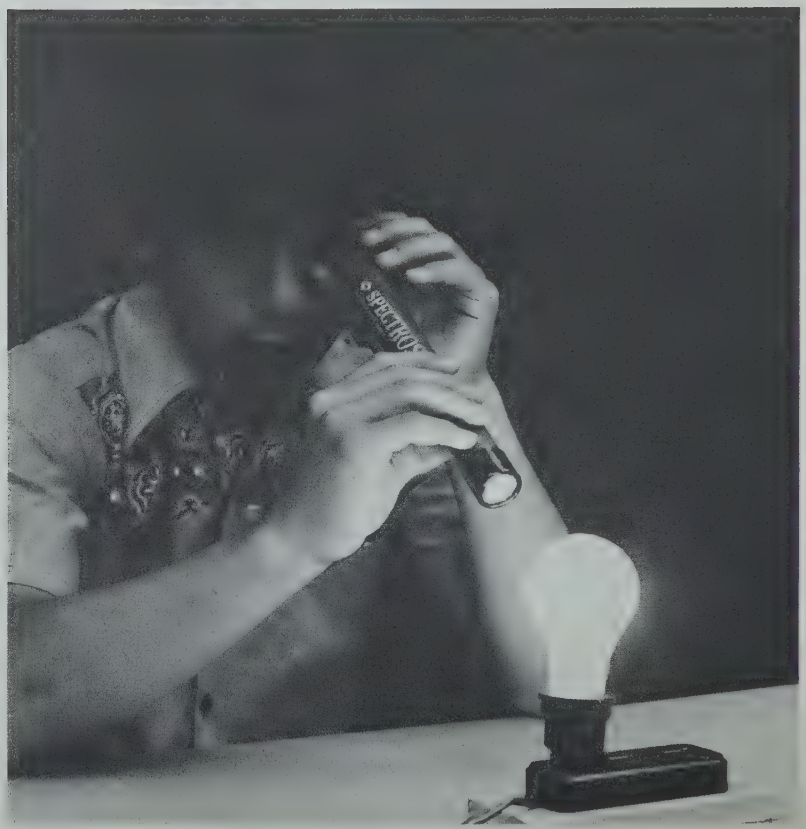
Fourth, you can check up on your own progress, Self-Evaluations are provided for each module chapter. You'll find them in the *Record Book*. And you'll find their answers there, too.

Working on Your Own

Your science class may be quite different from your other classes. This book, and others like it, will guide your study of science. Your teacher will not direct all your work. You'll be responsible for your progress. You'll also be responsible for taking good care of equipment and materials.

Begin each day's work where you left off the time before. Try to work ahead on your own or with your partner, if you have one. If you meet problems you can't solve, get help. But don't expect your teacher to give you the answers to the questions in the book.

After a few days, some of your classmates who are using this module may be ahead of you. Others may be behind. And other students will be studying different modules. This is how the course is supposed to work. No prizes will be given for being the first to finish a module. Work at a pace that is best for you. But be sure you understand what you have done before moving ahead.



Problem Breaks

Problem Breaks in modules give you a chance to be your own boss as you investigate. Some information and guidance are provided in each one. But you'll have to do the planning yourself. You'll often be expected to report your findings to your teacher and/or your classmates. Problem Breaks are important and should not be skipped. They aren't designed as just something else to do. They are central to what you are expected to learn in each module in which they appear. Their most important purpose is to help you learn how to think through a problem and design a method for solving it. The following comments may help you get the most out of doing Problem Breaks.

- Read the entire Problem Break carefully a couple of times before you do anything else. This will help you see how it fits in with what you've been doing. And it will tell you what you need and whether you should work with a partner. If you do work with a partner, do your planning together.
- Have the teacher check your plan of action before you start if the Problem Break includes an experiment to design. This can save you time and embarrassment. And it will ensure that what you want to do is safe for the classroom and doesn't demand too much equipment.

- Don't rush to get through a Problem Break. Most Problem Breaks are designed for one class period. But you may discover something on your own that you want to keep after for a while. That's fine. Talk it over with your teacher. Chances are you can keep on working as long as you want.
- Keep good records of what you do, observe, and conclude. Often you'll have to construct your own data tables, graphs, and maybe even equipment. Good records will be essential if you have to describe your work to others.
- Don't expect your teacher to have all the answers to the problems and questions in Problem Breaks. Most Problem Breaks are not designed to result in one answer to a question. How you go about your work will often determine the results you get. Other persons may get different results because they will probably choose a different plan of attack. And that is just the way it should be. Problem Breaks give everyone a chance to operate independently.

You can see that Problem Breaks are an essential part of the module design. Therefore, you can expect to see a question or two about each one in the Self-Evaluation section of the chapter in which it appears.

Safety in the Laboratory

This module will allow you to do several experiments. If you do them properly, they are perfectly safe. There are instructions and drawings to help you do each of the activities. But you should also observe the following rules:

- Equipment and chemicals should be used only in the classroom, unless your teacher gives you permission to use them elsewhere.
- Your work area should be left clean. Clean all equipment after use and return it to the supply area.
- Handle all chemicals carefully. Keep them away from your eyes, ears, nose, mouth, clothing, and skin.
- Read labels. Use chemicals only from containers that are clearly labeled.
- Wipe up spills with damp paper towels.
- Report any accidents immediately to your teacher.
- Throw waste materials into the proper containers.
- Wash your hands at the end of each laboratory period.
- Goggles should be worn when you are working with chemicals, when you are heating materials in test tubes, or when you could be harmed by flying objects.

What You Are Expected to Learn

During the year, you will work much as a scientist does. You should learn some useful information. More important, we hope that you will learn how to ask and answer questions about nature. Keep in mind that learning how to find answers to questions is just as valuable as learning the answers themselves—maybe even more valuable.

Do not write in this book unless it belongs to you. Do all your writing in your *Record Book*. Use your *Record Book* to check your progress with the Self-Evaluations.

From time to time, you will find that your answers to questions aren't the same as those of your classmates. Don't let that worry you. There are several right answers to some questions. And some questions may not have a correct answer. This may disappoint you at first. But soon you'll realize that there is much in science that isn't yet understood. So in this course, you will learn some things we don't know as well as some of the things we do know.

Filmstrip Key

Enrichment
Overcoming gravity

Up, Up, and Away

CHAPTER EMPHASIS:

The student uses a plastic water rocket as an introduction to the study of rocketry. Members of the team construct simple quadrants that enable them to measure the height attained by the rocket as a measure of performance. They then investigate the factors that affect this performance.

1

EQUIPMENT LIST

Per student-team

1 rocket, pump, and funnel
1 5-litre bucket
1 100-ml calibrated beaker
1 metrestick
1 40-cm piece of string
3 cardboards, 25 cm square
1 pair scissors
1 ruler
1 protractor
1 pencil

Per class

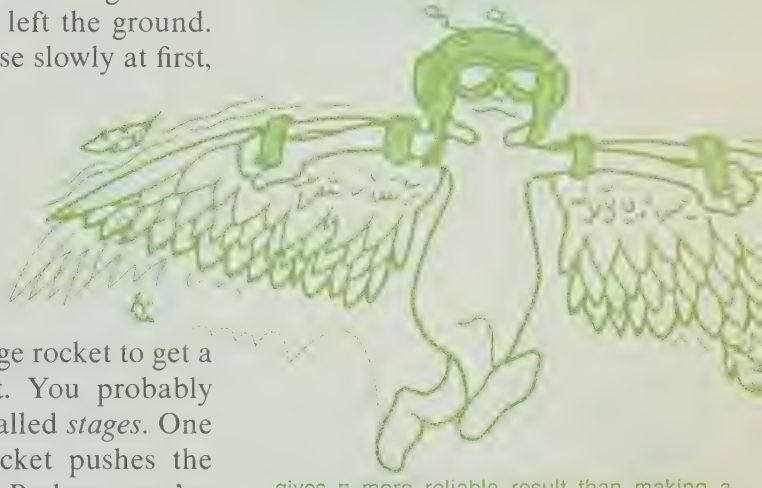
Oil or grease for pump

MAJOR POINTS

1. An obvious way to judge a rocket's performance is to measure the height it reaches after launch.
2. Making measurements indirectly is a useful and sometimes necessary technique of science; e.g., measuring angles and converting them to distance measurements.
3. Practicing techniques of experimenting is important in controlling the way variables change from one trial to another.
4. As with other measuring devices, making use of the quadrant as an instrument to measure height requires providing the quadrant with a scale and a zero point.
5. When using a quadrant in measuring height, averaging several measurements gives a more reliable result than making a single measurement.
6. Errors unique to one position or to one person can be reduced if two different observers in different places make the same measurement.
7. The performance of the water rocket (height of lift-off) is a function of the interaction of two variables—the amount of water and the amount of air pressure.

Most Americans have watched on television as rockets are launched into space from Cape Kennedy. You may have been fortunate enough to have been there yourself—seeing, hearing, and feeling the blast-off. You saw the long tail of flame streaming out behind the rocket as it left the ground. And you probably noticed that the rocket rose slowly at first, then faster and faster. Do you know why?

Try to have the students approach this important opening activity with the right attitude. Although they can enjoy the rocket launching, it shouldn't be only fun and games. The aim is to identify rocket performance, not just to go outside to play.



Maybe you've wondered why it takes a huge rocket to get a small spacecraft and three men into orbit. You probably know that the rockets are built in sections, called *stages*. One stage after another is discarded as the rocket pushes the spacecraft into orbit. Do you know why? Perhaps you've heard that a rocket engine works better out in space than it does in the earth's atmosphere. Is this really true?

To find the answers to questions such as those, you need some firsthand experience. First, you will launch a rocket to see what it takes to get it up. You and two other students will make up a launch team. Your team of three students should get the following equipment:

1 plastic water rocket, with pump and filler funnel
1 5-litre bucket, half full of water
1 100-ml calibrated beaker
1 metrestick

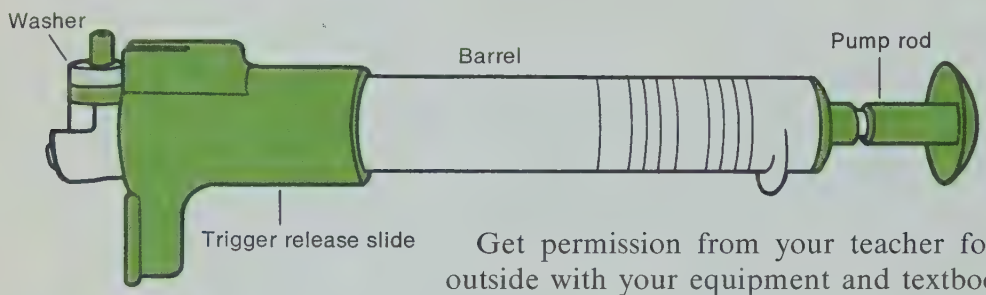
Be sure to clear with your school administration the procedure of students going outside for the launching. You will probably want to impress the students with their responsibility. It might be a good idea to have a briefing session for all students prior to any launching activity, in which you could discuss safety rules, launching procedures, and deportment while out of the classroom.

You may want to delegate the task of oiling or greasing the pump assembly in each class section. With the amount of use the rockets will get, it is important to keep the mechanism lubricated.

Before launching the rocket, read the following operating instructions carefully. Also, look back at them from time to time to be sure you are observing them. The rocket is breakable and should be handled carefully.

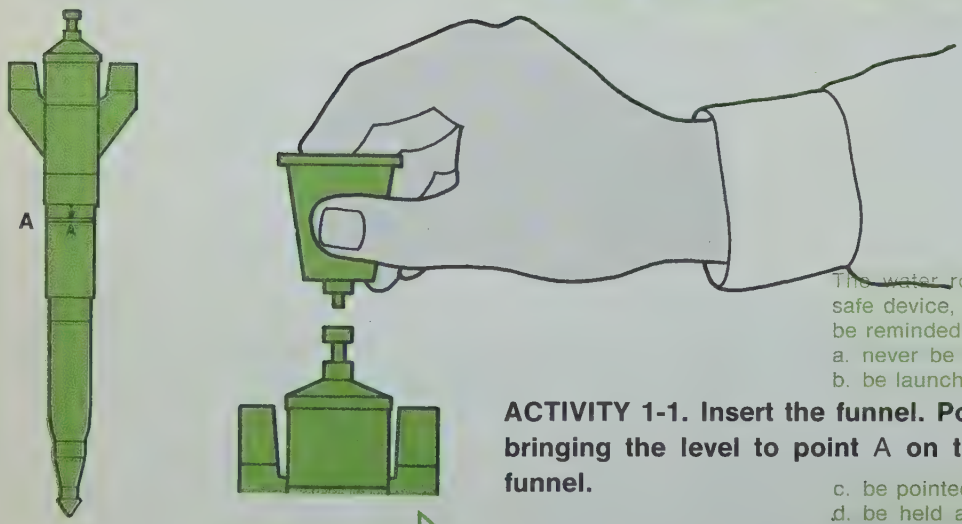
1. Use clean water in the rocket.
2. Keep all parts free of dirt and sand.
3. Apply oil or grease occasionally to the trigger release slide, barrel, and washer.
4. Keep the pump rod oiled with any fine machine oil.
5. Use cold water in the rocket. (Hot water could ruin the rocket.)
6. Avoid pumping more than 20 strokes into the rocket.

Figure 1-1



Get permission from your teacher for your team to go outside with your equipment and textbook.

Safety Note *You will need to go to a clear area away from buildings, trees, and wires. Try to find a spot about 30 metres from trees and structures.* **Do not point the rocket at people or windows, and don't lean over it yourself.**



The water rocket is basically a simple and safe device, but some students may need to be reminded that it should
a. never be pointed at people or buildings,
b. be launched only in a clear area,

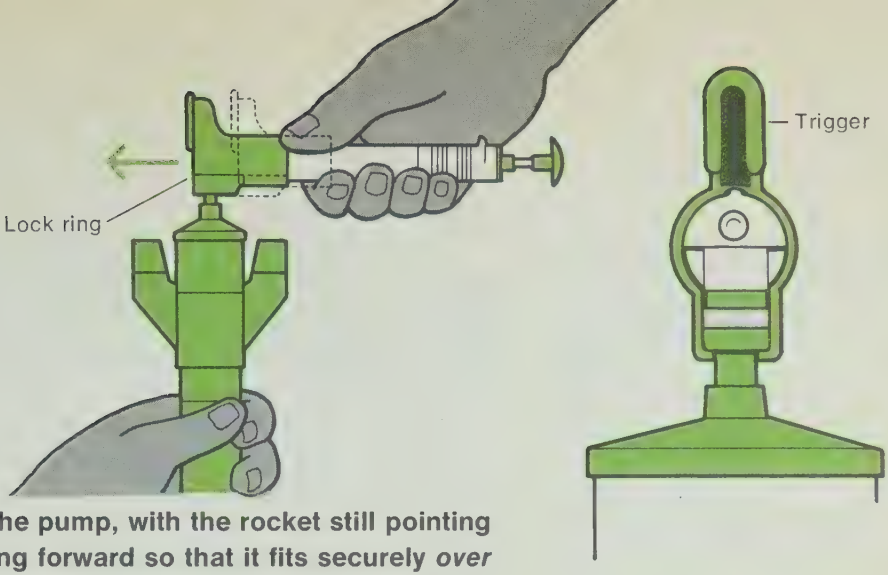
ACTIVITY 1-1. Insert the funnel. Pour in 50 ml of tap water, bringing the level to point A on the diagram. Remove the funnel.

c. be pointed straight up when launched,
d. be held at arm's length when launched,

RESOURCE

Need help in measuring in ml? Take a look at **Resource 2,** "More Metric Measures."

e. be kept clean and free of sand or dirt,
f. be supported on a solid object when launched,
g. be returned empty, with pump and funnel, at the conclusion of the activity, and
h. if possible, be launched so that it will not hit on concrete or macadam upon falling.

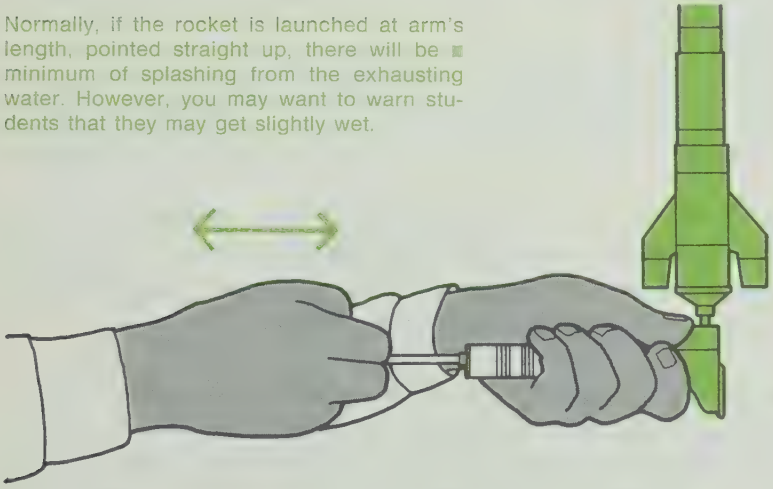


ACTIVITY 1-2. Attach the pump, with the rocket still pointing down. Push the lock ring forward so that it fits securely *over* the flanged end of the rocket, not just around it.

Experience has shown that the flanged end of the rocket is the part most apt to be damaged. If care is not taken to have the lock ring all the way over the flange, stresses set up during-pumping or launching can break off the flange and make the rocket unusable.

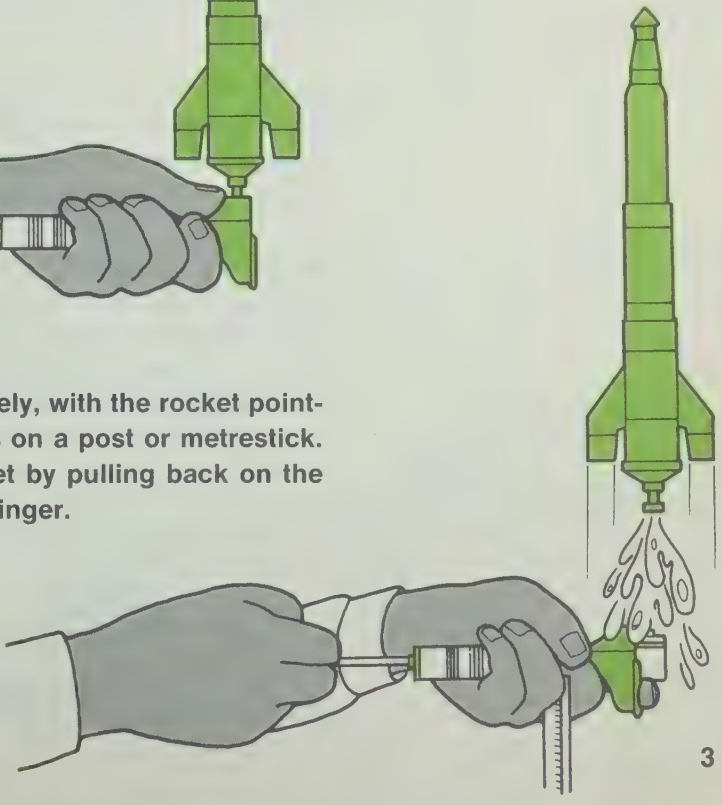
ACTIVITY 1-3. Turn the rocket skyward. Pump exactly 15 strokes. Ask the other team members to stand back.

Normally, if the rocket is launched at arm's length, pointed straight up, there will be a minimum of splashing from the exhausting water. However, you may want to warn students that they may get slightly wet.



ACTIVITY 1-4. Hold the pump securely, with the rocket pointing straight up. Support your hands on a post or metrestick. When all is clear, release the rocket by pulling back on the trigger release slide with your forefinger.

Note the use of a post or metrestick for support. A rigid box or carton will also work fine, and may afford some protection against the water.



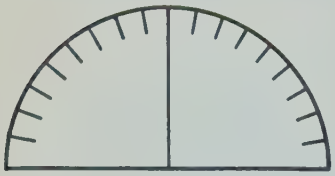
Generally it will require several trials before the rocket ascends vertically. The fins may be bent *with extreme care* to get proper spin and stabilize the flight. Wind is a factor, and in certain cases the rocket may have to be tilted slightly into the wind to counteract its effect.

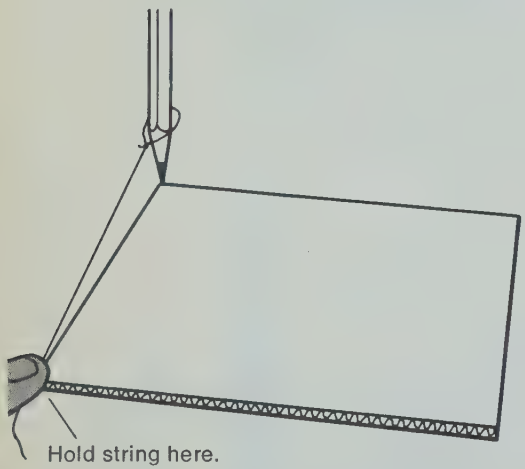
The launch was successful if the rocket moved almost straight up. Was your launch a success? If not, repeat Activities 1-1 through 1-4.

Once you have mastered getting a good launch, you are ready to begin your investigation of rocketry. You will try to find out what effect certain variables have on how high your rocket goes. To accomplish this, you need to be able to measure the launch height.

You and your partners should return to the classroom, where you will make a height-measuring instrument. Your team will need the following:

1 piece of string, 40 cm long
3 square pieces of cardboard, each at least 25 cm on an edge
1 pencil
1 pair of scissors
1 protractor
1 ruler



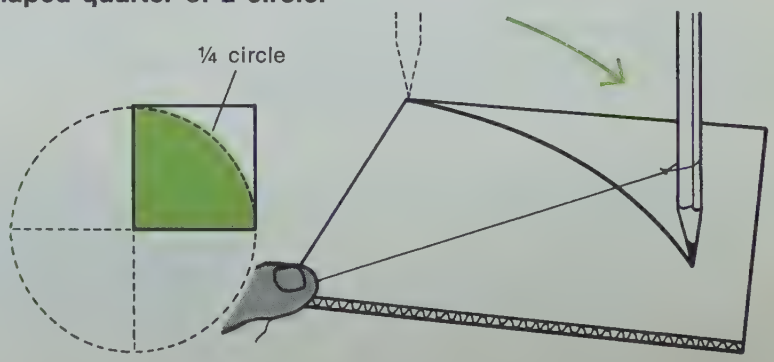


Continue to work with your partners, sharing the equipment as necessary. Each member of the team should make an individual height measurer from a piece of cardboard.

ACTIVITY 1-5. Tie a small loop in one end of the string. Slip the point of your pencil through the loop. Hold the pencil at one corner of the cardboard and stretch the string to the other corner. Hold it securely with your thumb.

ACTIVITY 1-6. Swing an arc with your pencil, letting it make a curve from corner to corner of the cardboard square. If the cardboard tends to slide, ask a partner to hold it securely as you draw. With the scissors, cut along the arc to get a pie-shaped quarter of a circle.

Encourage students to use reasonable care in making their quadrants. A sharp pencil is important in making the marks and drawing the lines.

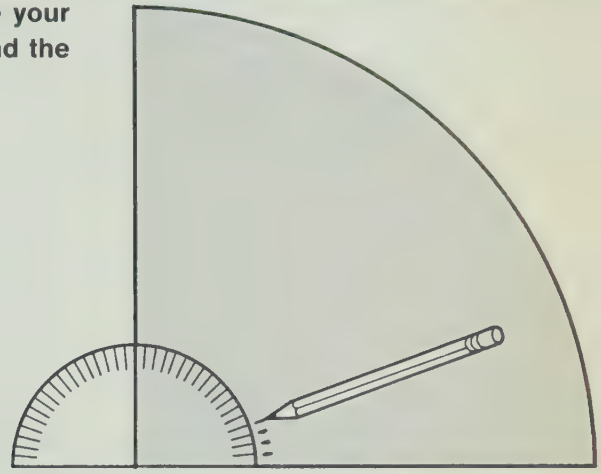


Can you use a protractor properly to measure angles? If you need help with it, do **Resource 9,** "Measuring Angles."

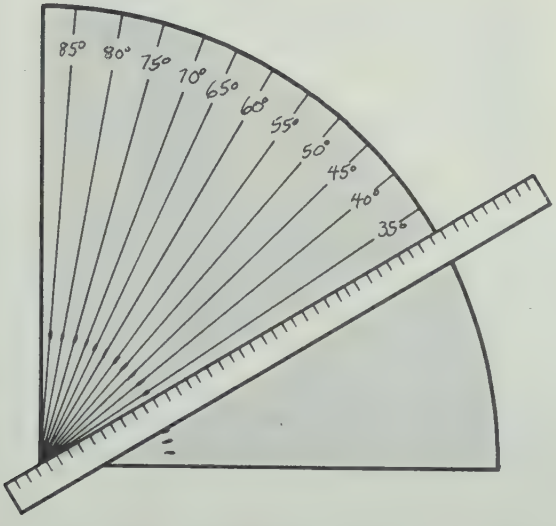
RESOURCE

Some schools may have large chalkboard protractors that could be used to draw the arc and mark off the degrees on the cardboard.

ACTIVITY 1-7. Place the protractor on your quarter-circle as shown. Starting at 0 degrees on your protractor, make a pencil mark on your cardboard every 5 degrees. Make your work as neat as you can. Your pencil must be sharp and the marks accurate.



ACTIVITY 1-8. Use a ruler or a straightedge to draw straight lines from the right-angle corner through each mark to the curved edge. Label the number of degrees on each line as shown.



The instrument you have constructed is called a *quadrant* because it is made from one fourth of a circle. Early mariners used simple wooden quadrants to measure the altitude angle of stars.

If some students have difficulty in using the quadrant, a simple activity may help. Have them level the quadrant by sighting on a mark on the chalkboard at eye height. Then, holding the quadrant level, they should sight on a light fixture, an upper corner of the room, or some other high point, marking the sight with their finger. From the same spot in the room, different students should be able to read approximately the same angle for a particular point. For good results, the center point (the right angle) of the quadrant must be close to the eye.

Now you are ready to collect data on your rocket launch. Your team will need your teacher's permission to go outside, as well as the following equipment:

3 cardboard quadrants
1 plastic water rocket, with pump and filler funnel
1 5-litre bucket, half full of cold, clean water
1 100-ml calibrated beaker
1 metrestick

Once again, take your equipment to an open area away from buildings, trees, and wires. Two members of your team will act as observers while the third member launches the rocket.

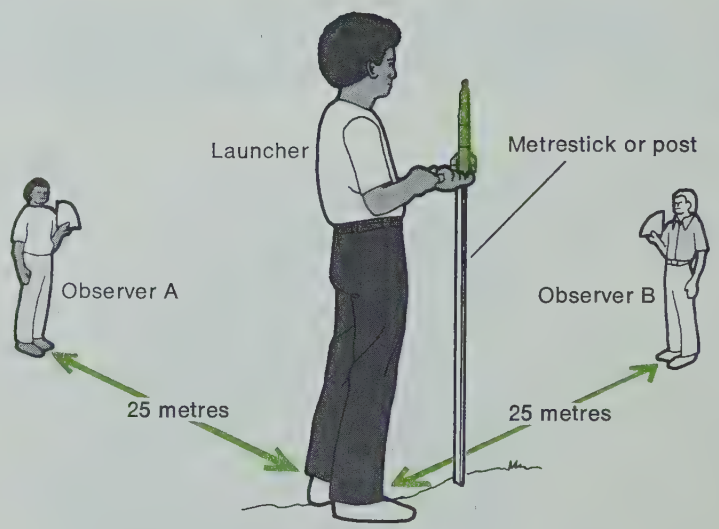
Before launch, each observer may want to practice sighting on some stationary objects.

The students can measure the 25-metre distances in different directions by pacing. It probably would help to have them practice getting a one-metre pace in the following manner.

Lay a metrestick flat on the ground. Practice taking a big step beside the stick, observing how much you have to stretch to pace off a metre with each stride.

Some teachers prefer to measure off 10 metres somewhere on the ground and mark it. Students can then practice until they can cover the distance in 10 strides.

ACTIVITY 1-9. When ready to launch, select a good site. Each observer should be 25 metres from that spot in different directions.



ACTIVITY 1-10. Observers should hold the quadrants on edge with the center point at eye level. Crouch down if necessary. The bottom of the quadrant should be about the same distance above the ground as the rocket. Sight along the bottom edge directly at the bottom of the rocket. Then the launcher should repeat the launch procedure given in Activity 1-4. If enough metresticks are available, you may want to rest the quadrant on one to steady it.

ACTIVITY 1-11. Hold the quadrant steady with one hand as the rocket is launched. Move the first finger of the other hand along the edge of the quadrant. Follow the rocket's flight until it reaches the highest altitude. Keep your finger at that point until you can read the number of degrees. Record that number.

☐**1-1.** What angle did Observer A get? What angle did Observer B get?

☐**1-2.** Did each observer get the same number of degrees?

☐**1-3.** If your answer to question 1-2 was No, what reasons can you give for the difference?

1-3 Some possible reasons for the difference:
1. The rocket didn't go straight up, thus putting it closer to one observer at sighting.
2. Error in measuring 25 metres.
3. Error in using the quadrant, such as
   a. not keeping it close to the eye,
   b. not holding it level,
   c. not following the flight properly with the finger, or
   d. incorrectly reading the scale.

This is a good question to see if students can spot experimental error. It is reasonable to expect differences in readings. They are using a rather crude instrument.

If you have time, you may want to repeat Activities 1-10 and 1-11 to check your results. You may want to take turns launching so that each member of your team gets to use a quadrant.

Using Table 1-1, an observer 25 metres away from the launch site can find out how high the rocket went. The height in metres appears directly below the last observed angle.

Table 1-1

Height converter for observer at 25 metres									
Angle	0°	5°	10°	15°	20°	25°	30°	35°	40°
Height	0 m	2.2 m	4.4 m	6.9 m	9.1 m	11.7 m	14.4 m	17.5 m	21.0 m
Angle	45°	50°	55°	60°	65°	70°	75°	80°	85°
Height	25.0 m	29.8 m	35.7 m	43.3 m	53.6 m	68.7 m	93.3 m	141.8 m	285.8 m

☐**1-4.** What height corresponds to the angle measured by Observer A?

You may want to point out (perhaps with small-group discussion) that the procedure of averaging is one way of minimizing experimental error and of taking care of the differences in readings.

☐**1-5.** What height corresponds to the angle measured by Observer B?

☐**1-6.** What is the average of the two heights?

RESOURCE

Know how to find an average? **Resource 4,** "Averaging," can be a big help. Take a look at it now.

Were you able to get the rocket to go nearly straight up? Did the observers measure about the same angle? Then consider your launch a success.

Now back to the question you need to answer: What variables affect how high the rocket goes? To express it another way: What thing or things can be changed to make the rocket go higher?

From time to time in this module, you will be asked to do Problem Breaks. These are problems for you to solve, without much help from your book or from your teacher. The problems will usually help you understand what you are studying in the chapter. But that's not their major purpose. They are designed to give you practice in problem solving and in setting up your own experiments. You should try every Problem Break—even the tough ones. And in most cases you should have your teacher approve your plan before trying it. The first Problem Break in this module is next.

Problem Break 1-1 is the payoff for the chapter. Encourage students to have a well-planned procedure written in the Record Book, along with expected results (hypothesis). Note that your okay is called for before they proceed.

Better students may intuitively realize that maximum performance results from using maximum pressure (20 strokes of the pump) and just enough water so that it is all exhausted from the rocket. They can find this amount of water by increasing the amount in successive trials until the rocket returns to the earth with some water remaining in it. A reduction by this amount of water should give maximum height. (Don't give this answer away to them, however.) This is true because the mass of any excess water has to be lifted by the rocket, and it therefore subtracts from the performance.

RESOURCE

PROBLEM BREAK 1-1

The water that was forced out of the rocket must have had something to do with the rocket's going up. The air that was forced into the rocket must also have been important. These two factors should be investigated to determine their effect on the height that the rocket reaches. Design an experiment that will allow you to measure the effect of these two variables. You will probably want to use several different amounts of water (measured in millilitres) and air (measured by the number of pump strokes). However, investigate only one of the variables at a time. Control (keep constant) all other variables.

Do you need help in setting up an experiment? If you do, go to **Resource 6,** "Investigating Variables" for help. You'll be investigating variables in several cases in this module.

Try to find two other people to work with as a team. Outline your procedure in your Record Book. Describe in a few words what you plan to do and what you expect to

happen. Then get your teacher's permission to try your experiments. Record your data carefully, including the number of ml of water you used to reach maximum height. You will need this amount in Chapter 3. Be sure to use two observers to measure the height the rocket reaches. This height is a measure of performance of the rocket. Follow the steps for rocket launching in Activities 1-1 through 1-4.

Caution *In working with the variable of amount of air, don't over-pump the rocket. Twenty strokes is the suggested maximum.*

☐**1-7.** Describe how increasing the amount of water affects the height reached by the rocket.

☐**1-8.** Describe how changing the amount of air affects the height reached by the rocket.

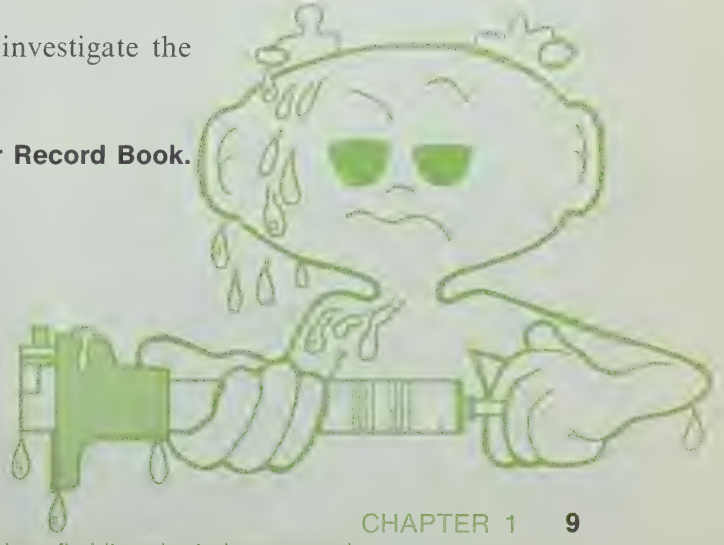
The descriptions in questions 1-7 and 1-8 will vary, but hopefully the student will discover a relationship somewhat similar to that explained in the teacher note on the preceding page.

In Problem Break 1-1, you have learned what effect two variables can have on how high the rocket goes. But you may still wonder why these variables cause the rocket to go up at all. Just why should water and air make it rise? Something about the combination of these variables influences the rocket by giving it a push upward.

☐**1-9.** How do air, under pressure, and water cause an upward push on the rocket? There is a space provided in your Record Book to give your own ideas.

To check your ideas, you will continue to investigate the upward push in the next two chapters.

Before going on, do Self Evaluation 1 in your Record Book.



GET IT READY NOW FOR CHAPTER 2

This next chapter uses the longest list of equipment of the whole module. Three rocket test stands, each with two pails, tubing, clamp, force measurer with plastic blade and jet, take time to assemble. You may want to put them together ahead of time or delegate the responsibility to capable students. Directions for assembly are given in the chapter. Provisions must be made for supporting the supply pails 2 metres above the jets. The equipment list also calls for baby-food jars and a watch or timer that must be supplied locally..

Some teachers find it easier to have several force measurers with thin blade, scale, angle bracket, and clamp assembled instead of having the separate components for Activity 2-1.

UNITED STATES
USA
USA

What a Reaction!

2

CHAPTER EMPHASIS

Material rushing out of an opening causes an unbalanced force that tends to move a body in the opposite direction. This force is dependent upon both the mass of material thrown out per second and the speed at which it is thrown. The force decreases when the jet discharges into a denser medium.

EQUIPMENT LIST

Per student-team

1 balloon (spherical)
1 stopper, 1-hole, rubber
1 force measurer, 0–1 N scale
1 angle bracket, 2 bolts, 2 wing nuts
1 clamp
1 water rocket, pump, funnel
1 5-litre pail, with hose fitting
1 5-litre pail, without fitting
1 2-m plastic tube
1 reducer tube
1 60-cm piece of rubber tubing
1 jet tube (of each size hole)
1 plastic strip with holes
1 screw clamp
1 blank force measurer card
1 baby-food jar or cup
1 100-ml graduated beaker
1 washer
Masking tape
Watch or timer

A Saturn-Apollo rocket is a very large object. It stands more than 100 metres tall and has a base about 10 metres in diameter. When fueled, it weighs 2730 metric tons—as much as 24 diesel-electric freight locomotives.

Yet when the tail of flame shoots out of the base, this rocket heads into the sky. How is this immense machine able to get off the ground? Where does all the upward push come from? To answer this question, you need to look at a very much smaller and simpler push.

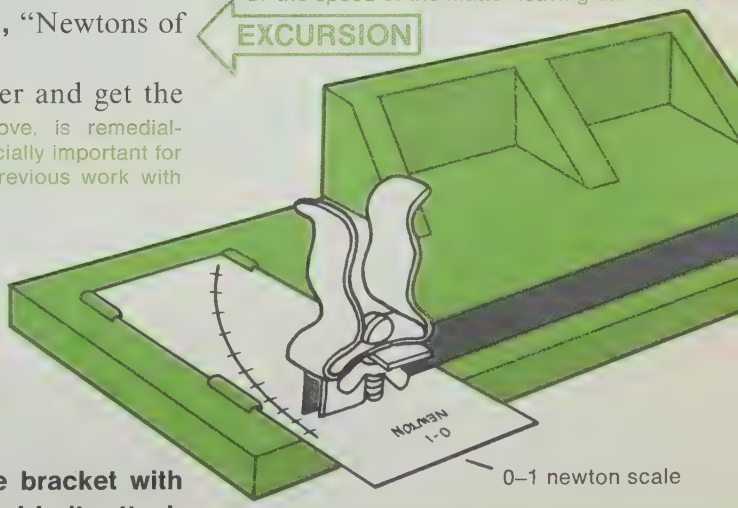
A push is a force. So is a pull. You will be working with such forces throughout much of this module. Therefore, you'd better know how to measure them. Perhaps you already do. In fact you may have used a special force-measuring device previously. If not, do **Excursion 2-1,** "Newtons of Force" before going ahead in this chapter.

EXCURSION

Excursion 2-1, keyed above, is remedial-review on forces. It is especially important for those who have had no previous work with forces.

Now back to that small push. Find a partner and get the following equipment:

1 balloon
1 one-hole rubber stopper (#1)
*1 force measurer, with thin blade
*1 0–1 newton scale
*1 angle bracket, with 2 bolts and 2 wing nuts
*1 clamp
*May be already put together



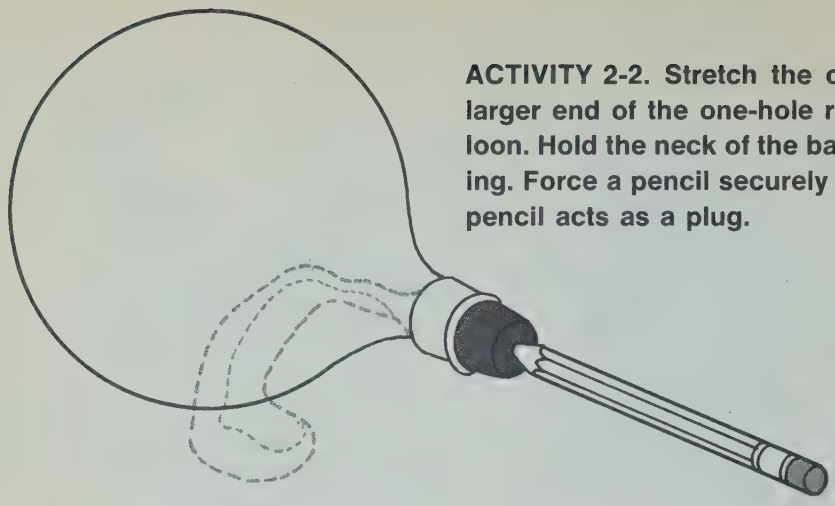
0–1 newton scale

ACTIVITY 2-1. Fasten the clamp on the angle bracket with bolt and wing nut. Using the remaining nut and bolt, attach the angle bracket to the end of the force-measurer blade. Be sure to use the thin blade and the 0–1 newton scale.

MAJOR POINTS

1. In studying a complex phenomenon, it is often useful to investigate a simplified form of the phenomenon; e.g., the effect of escaping gases on rocket propulsion is studied by releasing air from a small inflated balloon. The purposes of using a smaller system are (1) to decrease the expense and time of investigation, (2) to have a more manageable and easily observed system, and (3) to control variables more easily.
2. A gas in a closed container exerts pressure in all directions on the inside walls.
3. When gas under pressure in a container is allowed to rush out of an opening, an unbalanced force is exerted on the opposite wall, and this tends to move the chamber in the direction of that unbalanced force. This force can be measured by using a force measurer.
4. To measure the force (which is small in the balloon system), you must first zero the scale.
5. The motion of a rocket is *not* due to the force exerted by the escaping gas on the gas outside the rocket.
6. The magnitude of the force that moves a rocket depends on (is directly related to)
   a. the mass of fuel lost from the rocket/sec, and
   b. the speed of the matter leaving the rocket. (With a constant-size opening for matter to rush out of, the mass of matter per second and the speed of the matter rushing out are directly related.)
7. An explanation is reached for the relationship of water-rocket performance to the variables of air pressure and water volume.
8. Graphing again proves to be a useful tool in analyzing relationships between variables.

cales such as the one made to measure force of a water jet involve a unit size h is unique to that apparatus. Such a e is useful for solving a specific problem, but the measurement data cannot be meaningfully compared with other data.
10. Major point 7 of Chapter 1 is a major point of this chapter also.



ACTIVITY 2-2. Stretch the opening of the balloon over the larger end of the one-hole rubber stopper. Blow up the balloon. Hold the neck of the balloon to keep the air from escaping. Force a pencil securely into the hole in the stopper. The pencil acts as a plug.

If the balloon rests too heavily on the force measurer, a short piece of tape may be fastened from the inflated balloon to the stopper to hold it up.

ACTIVITY 2-3. Slide the stopper into the clamp on the force measurer. Zero the 0–1 N scale. Although the balloon may rest on the force measurer or the table, the blade must be free to move. Now carefully remove the pencil by twisting it and observe what happens to the blade as the air escapes.

☐**2-1.** Does the force measurer indicate that a force is acting when the pencil is in the stopper?

☐**2-2.** Does the force measurer indicate that a force is acting when the pencil is removed?

Repeat Activities 2-2 and 2-3 and try to measure any change you observe.

Normally, the force from the air rushing out will be about 0.1 newton (question 2-4). Of course, it is in the opposite direction, which is a lead-in to the idea of action and reaction (question 2-3).

☐**2-3.** What was the direction of the force acting on the blade? Was it the same as, or opposite to, the direction of the air as it rushed out?

☐**2-4.** How much force was acting?

Figures 2-1 through 2-3 may help to explain what you observed. With the balloon inflated, the air inside exerts the same force in all directions. This force is due to air *pressure.* The air pushes outward against the sides of the balloon. And it pushes against the end of the pencil that closes the hole in the stopper. Only eight force arrows are shown in the diagram, but actually they can be considered to be countless. Since equal forces act in all directions, the forces are in balance. Thus, the balloon does not move. Its sides are merely pushed outward against the outside air, which pushes back.

When the pencil is removed from the stopper, air rushes out. The air within the balloon continues to push on the inside of the balloon in all directions. At the outlet, however, there is no balloon to push on. With the force still pushing on the inside of the balloon at the point opposite the outlet, you have an *unbalanced* force condition. This *unbalanced* force causes the balloon to move, pulling the force-measurer blade in that direction.

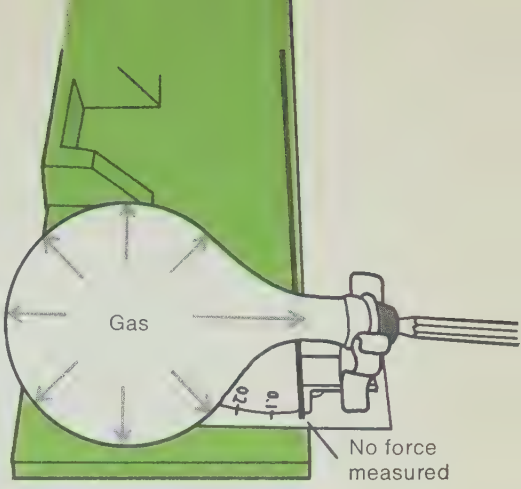


Figure 2-1

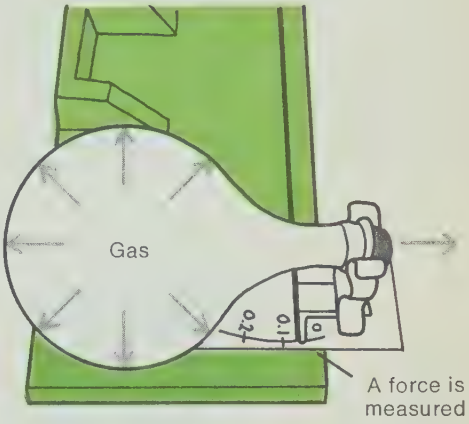


Figure 2-2

Strictly speaking, pressure is force per unit area. The force arrows in the figures are only pictorial and do not represent actual magnitude. Of course, the larger the outlet, the greater the unbalanced force, but it would last for a shorter time.

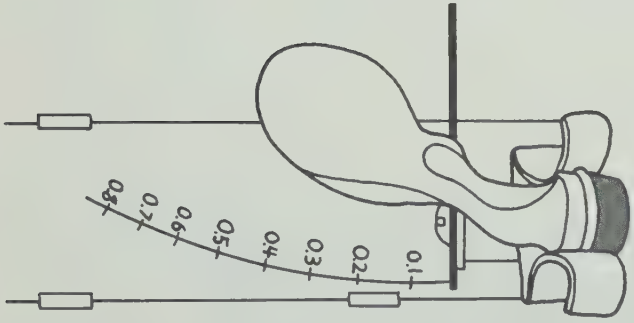


Figure 2-3

As the air continues to rush out, the pressure (forces) inside the balloon gets smaller. Eventually, it drops to zero. With no force inside the balloon, the walls collapse and movement stops. The blade then returns to zero.

How does this idea of pressure on the inside and unbalanced force apply to your water rocket?

☐**2-5.** Suppose the rocket has been loaded, has been pumped with air, and is ready for launch. Are the inside forces in balance?

☐**2-6.** When the trigger release slide is pulled, the water rocket rises into the air. What unbalanced force acting on the water rocket causes it to move?

☐**2-7.** What could you do to increase this unbalanced force?

If you had trouble with the last two or three questions, think back to Problem Break 1-1. You found that changing the amount of pressure (pump strokes) or the amount of water affected the rocket's performance. Both variables affected how high the rocket rose.

Encourage students to answer questions 2-8 and 2-9 before doing Problem Break 2-1. And in the Problem Break, it would probably not be necessary for students to go outside for the test. With water only, it will not rise at all, and with air only, it will not rise more than one or two metres. However, the students should discover this for themselves, and telling them not to go outside will probably give it away.

☐**2-8.** Suppose you filled the rocket with water but pumped in no air, and then pulled the trigger release slide. Would the rocket have risen?

☐**2-9.** Suppose you added no water to the rocket, but pumped 15 strokes of air into it. Then you pulled the trigger release slide. Would there be any upward unbalanced force on the rocket?

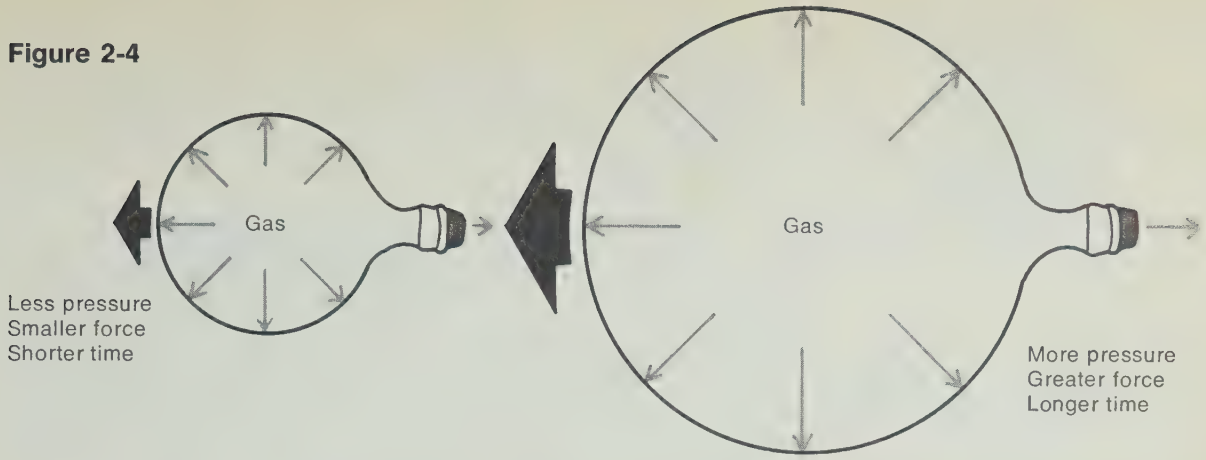
Check your answers to questions 2-8 and 2-9 by doing Problem Break 2-1.

PROBLEM BREAK 2-1

Find out how high the water rocket will go when filled with water but not pumped. Then find out how high it goes when pumped with air but carrying no water. Record the results of your investigation in your Record Book.

In the case of your water rocket, it isn't hard to see how air pressure can change the unbalanced lift force. Think back to the balloon activity. If you put more gas (air) into the balloon, there would be more gas to come out. This would give you an unbalanced force for a longer time. In addition, the gas in the balloon would have greater pressure. This would cause a greater unbalanced force to push the balloon forward. Figure 2-4 illustrates this.

Figure 2-4

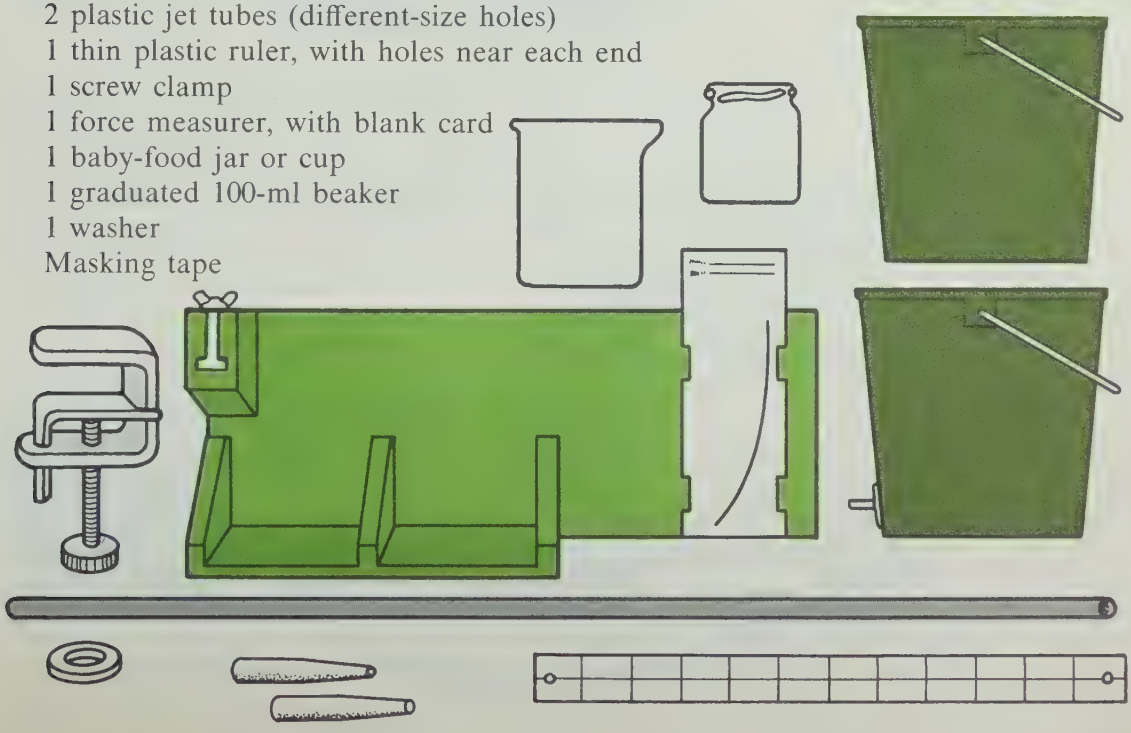


But why does the water have such an important effect on the unbalanced lift force? The rocket just won't go far at all without the water. The effect of air pressure and water on lift force must be closely related. To observe this relationship in the water rocket is very difficult. Things just happen too fast. You need a simpler system, which can be controlled. Such a system is the rocket test stand. To prepare one, you should work with two partners again. Your team will need the following equipment:

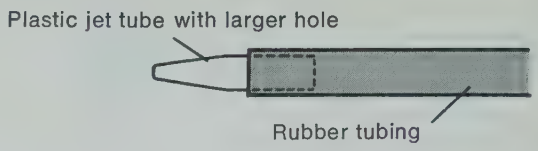
1 water-flow kit
2 plastic jet tubes (different-size holes)
1 thin plastic ruler, with holes near each end
1 screw clamp
1 force measurer, with blank card
1 baby-food jar or cup
1 graduated 100-ml beaker
1 washer
Masking tape

Once again, Figure 2-4 is a pictorial representation only. Because of the extreme elasticity of the balloon, the pressure is not necessarily directly related to size.

The water-flow kit in the equipment list consists of the two plastic pails (one with a hose fitting), the 2-metre plastic tube, the reducer tube, and the 60-cm rubber tubing. You may want to have all the apparatus assembled ahead of time, but in any case you will want the parts listed in the water-flow kit assembled. The reducer tube connects the plastic tube and the rubber tubing.

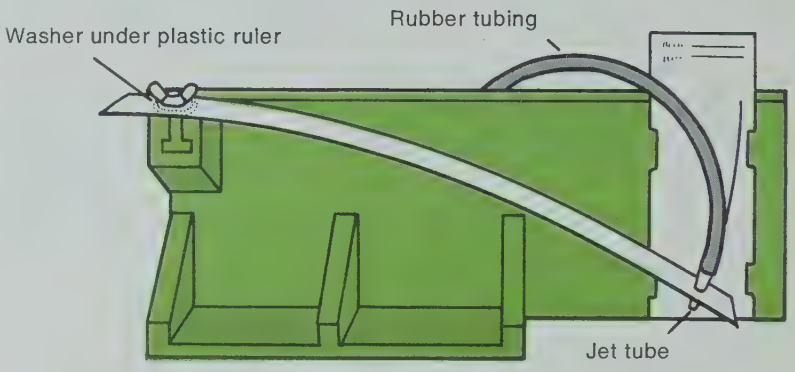


ACTIVITY 2-4. Use the jet tube with the larger hole first. Slide the large end of the plastic jet tube about 1 cm into the open end of the rubber tubing.

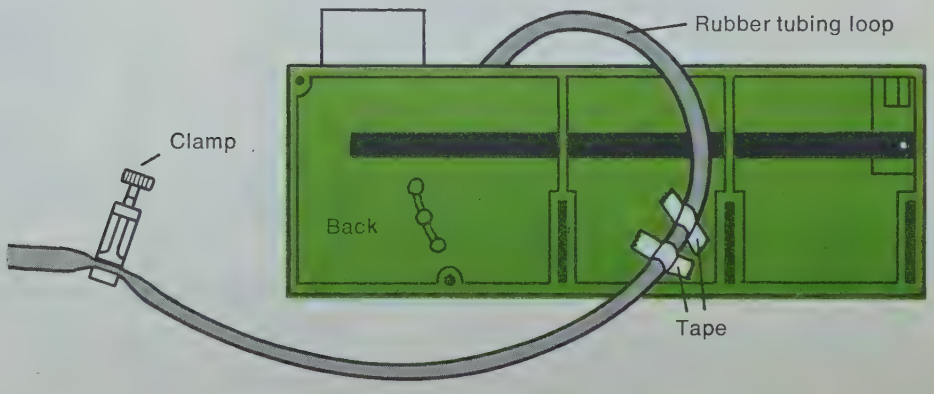


Once assembled, the water jet apparatus can be left together until all students have used it. The following points are important.
1. Be sure all fittings are watertight.
2. Be sure the plastic blade is free to move when the jet and rubber tubing are added. This entails sliding the rubber tubing through the two pieces of tape until just the right-size loop is obtained.
3. The supply bucket must be located about 2 metres above the jet. It could sit on top of a tall cabinet or on a high shelf, or hang from a wall bracket. With water in the pail, it will have a mass less than 5 kg, so it could even hang from a light fixture with rope or twine. Some of the tests will be made with the pail at the 2-metre height, other tests at half that height.

ACTIVITY 2-5. Remove the steel blade from the force measurer. Put a washer and then the plastic ruler on the bolt. Replace the wing nut. Insert the jet tube in the hole at the other end, with the jet pointing downward.



ACTIVITY 2-6. Loop the rubber tubing over the top of the force measurer, and fasten it to the back with tape. Be sure that the loop is large enough to clear the force-measurer blade, thus allowing it to move freely. Slide a screw clamp onto the rubber tubing and tighten the screw, closing the tube.



You are ready for the final step in setting up the rocket test stand. For the first tests, the water-source bucket should be about 2 metres above the jet outlet. Your teacher can help you with the setup for your particular classroom. Figure 2-5 shows the complete setup.

The force measurer should rest on top of the catch bucket. Be sure that the plastic tubing is attached securely to the drain on the supply bucket. Be sure, also, that the screw clamp pinches the rubber tubing, closing it. Then fill the supply bucket with water.

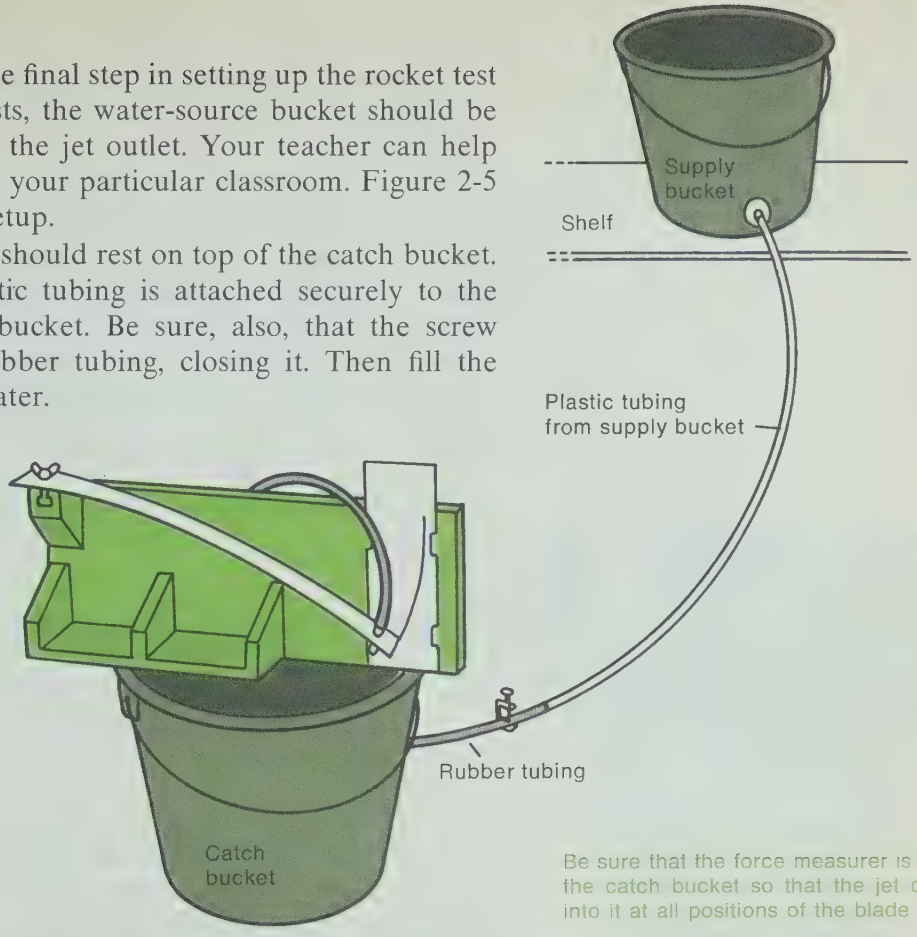
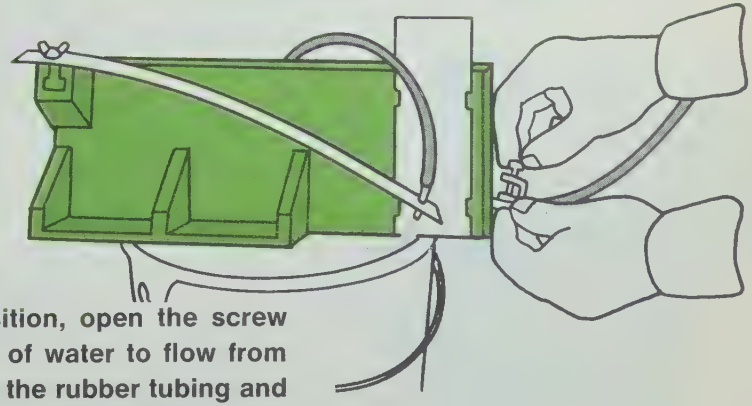


Figure 2-5

Be sure that the force measurer is placed on the catch bucket so that the jet discharges into it at all positions of the blade

Caution *Check your tubing to see that there are no leaks.*



Properly adjusted, the rubber tubing furnishes some of the support for the jet and the blade.

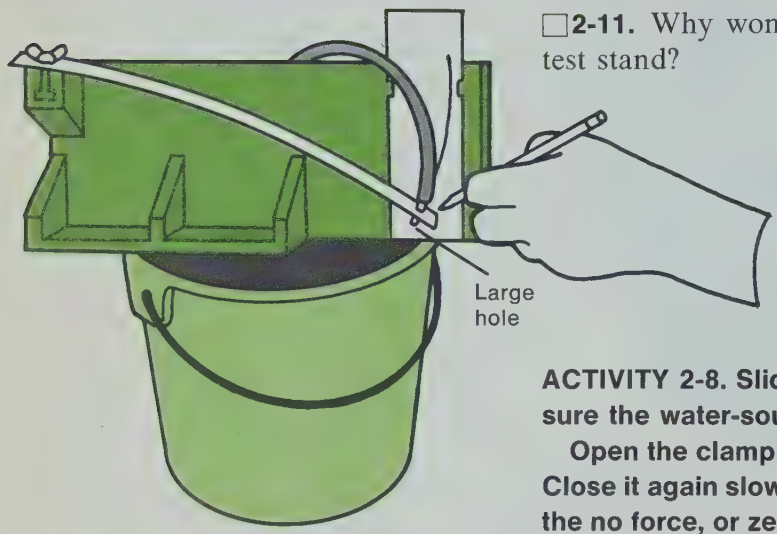
ACTIVITY 2-7. With everything in position, open the screw clamp slowly to allow a small stream of water to flow from the jet. If necessary, adjust the loop in the rubber tubing and the tape on the back of the force measurer. The blade should move freely in a position about like that shown. Be sure the blade does not rest on the bottom support. Allow the water to run until all air bubbles are out of the tubing. Then close the screw clamp again.

As an item of interest, but not necessarily for the student, full-scale deflection of the plastic blade requires a force of about 0.1 newton. This means that it is sensitive to forces about $\frac{1}{10}$ as great as the thin steel blade, and about $\frac{1}{100}$ as great as the thick one.

☐**2-10.** As you opened the screw clamp, what happened to the plastic force-measurer blade?

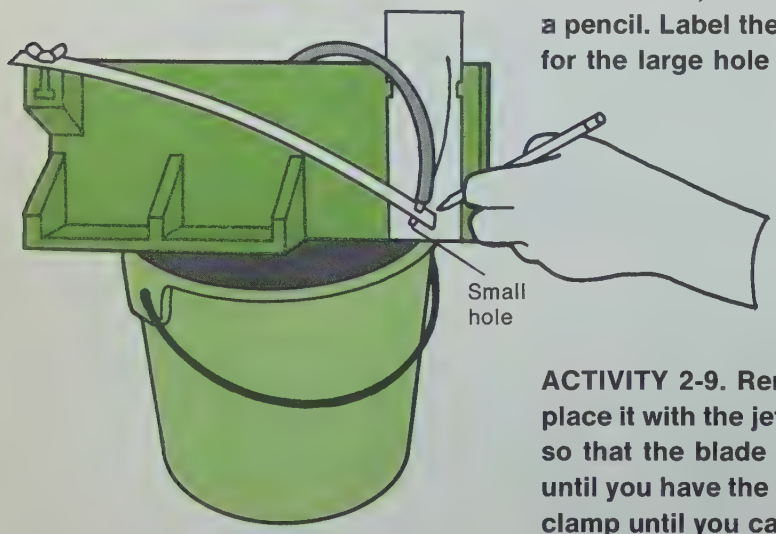
As you opened the screw clamp, you should have noticed an effect on the blade. It moved up. Some force lifted the blade to a higher position. You can try Activity 2-7 again if you wish. When water flows through the jet, a lift force is produced. This is like the lift force that occurs when water shoots out of your rocket. Your rocket test stand is an apparatus you can use to measure that lift force. All it needs is a scale.

☐**2-11.** Why won't your newton scale work for the rocket test stand?



ACTIVITY 2-8. Slide a blank card into the force measurer. Be sure the water-source bucket is filled.

Open the clamp slowly until you have the full flow of water. Close it again slowly. Do this several times until you can mark the no force, or zero, point and the maximum force point with a pencil. Label the maximum force point with an "L" to stand for the large hole in the jet.



ACTIVITY 2-9. Remove the jet tube with the larger hole. Replace it with the jet tube with the smaller hole. Adjust the card so that the blade is at the zero point. Then open the clamp until you have the full flow of water again. Open and close the clamp until you can mark the maximum force point for the jet with the smaller hole. Mark the point with an "S."

☐**2-12.** Which jet tube gave a greater maximum force point?

☐**2-13.** About how many times as great was the larger force than the smaller force?

Why should the size of the hole in the jet tube have such an effect on the force? What does the hole size do?

☐**2-14.** From which jet tube do you think more water flows in a given time?

You need to be sure about question 2-14. To get a definite answer, do Problem Break 2-2.

PROBLEM BREAK 2-2

With your two partners, determine the amount of water that comes out of each jet tube per second. Start with the smaller hole. A suggested procedure follows:

1. One person should act as timer, another as the catcher of the water. The third can be operator of the screw clamp.
2. Open the clamp all the way. Water should flow out of the jet and into the catch bucket.
3. When the timer says "Start!" shove the jar or cup under the jet. Catch the water for 5 seconds. At the signal from the timer, simply remove the cup. Then the operator can close the clamp.
4. Using a container with a ml scale, measure the amount of water caught in the jar.
5. Divide the number of ml by 5 to determine the amount of water per second. If you need help with a decimal answer, look at **Resource 3,** "Decimal Dealings."
6. Repeat the procedure two more times and average the three readings. If you need help in averaging, see **Resource 4.**

☐**2-15.** What is the average ml of water per second from the small jet?

Encourage students to follow the procedure carefully. If they can see that there is a relationship between the amount of water per second and the lift force on the jet, they will have grasped one of the two factors that causes the rocket to leave the ground.

RESOURCE

RESOURCE

7. Replace the small jet with the larger one. Repeat the entire procedure, and find the average amount per second for the larger jet.

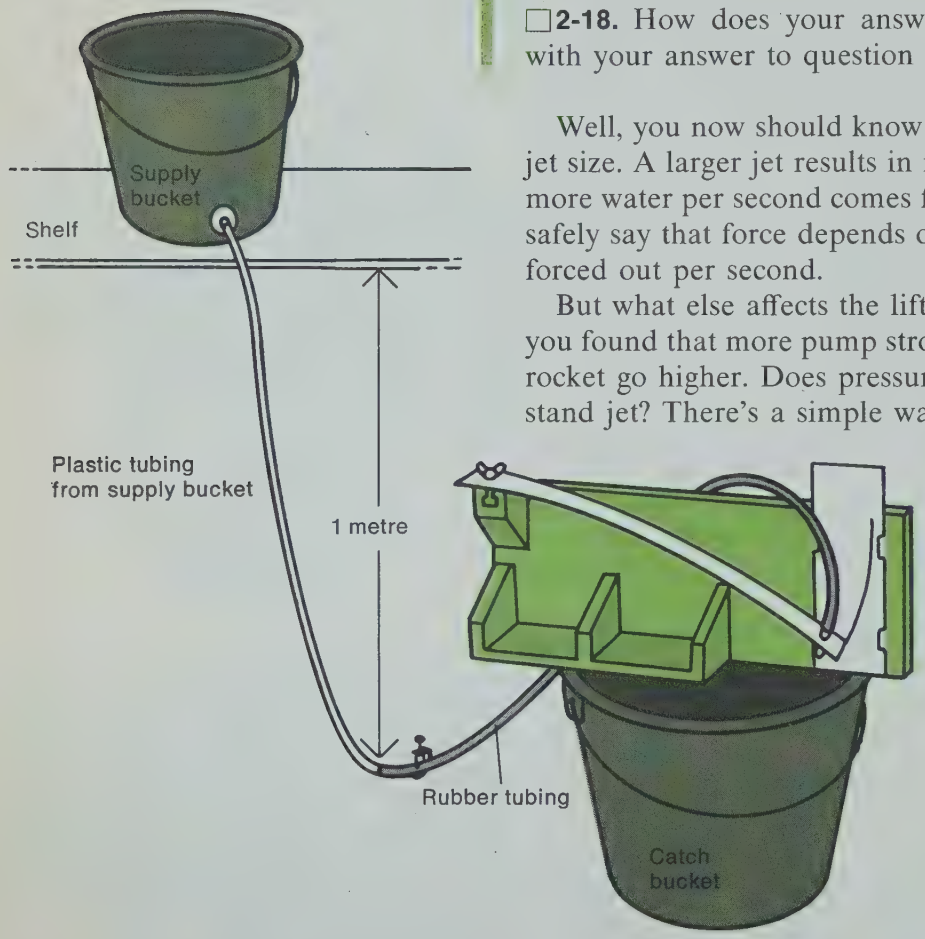
☐**2-16.** What is the average ml of water per second from the larger jet?

☐**2-17.** About how many times as great was the amount from the larger jet than the amount from the smaller jet?

☐**2-18.** How does your answer to question 2-17 compare with your answer to question 2-13?

Well, you now should know something about the effect of jet size. A larger jet results in more force. At the same time, more water per second comes from the larger jet. So you can safely say that force depends on the amount of water that is forced out per second.

But what else affects the lift force? With the water rocket you found that more pump strokes (more pressure) made the rocket go higher. Does pressure affect the force on the test-stand jet? There's a simple way you can find out.



Here's the chance for students to find out the second factor that affects lift force—speed of flow, which is dependent on pressure.

ACTIVITY 2-10. Zero the blade with the large jet in place. Lower the supply pail so that it is only half as high (1 m) above the jet as before. Open the clamp and note the maximum force point. Close the clamp.

☐**2-19.** How did lowering the supply pail affect the maximum force?

The pressure on the jet depends on the height of the supply pail above it. The higher the pail, the greater the pressure.

☐**2-20.** What is the effect on the lift force of decreasing the pressure?

When there is more pressure on the water—more push—the water comes out of the jet faster. The speed of the water stream is greater. Therefore, speed of the ejected water has an effect on the lift force.

☐**2-21.** What is the effect on the lift force of decreasing water speed?

To sum up, your rocket test stand has shown you that FORCE depends on the amount of water per second, and the speed that the water comes out. Put together, this becomes:

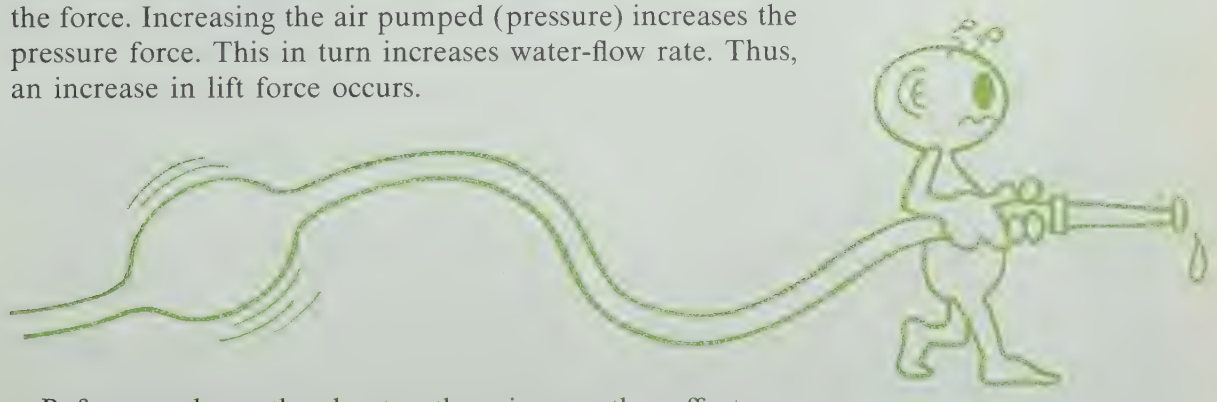
FORCE depends on amount of water per second times speed of flow.

Mathematically, the combined relationship of amount of water per second and speed of flow is

$$F = \frac{m}{\Delta t} \times \Delta v.$$

The amount is really mass measured in kilograms, but of course the measured amount in ml is easily converted to mass in kilograms.

You have also answered the basic question asked in this chapter: How do pumped air and water affect the lift force on the water rocket? The steady flow of water out of the rocket provides a lifting force. The faster the flow, the greater the force. Increasing the air pumped (pressure) increases the pressure force. This in turn increases water-flow rate. Thus, an increase in lift force occurs.

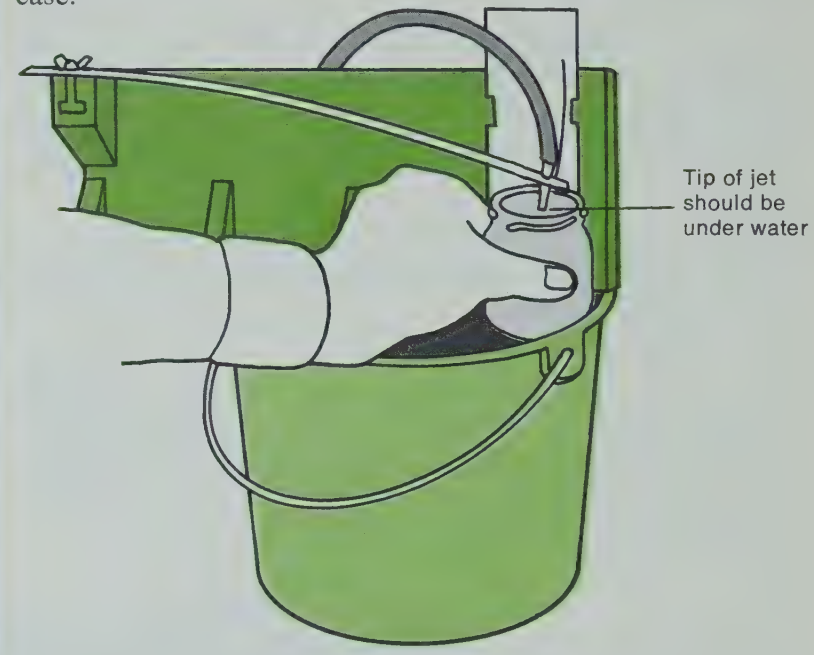


Before you leave the chapter, there is one other effect you should investigate. Problem Break 2-3 deals with an important error that some people make when they think about rockets.

Problem Break 2-3, though short, is important in its application in rocketry. The student should see that the force on the jet is decreased when it discharges under water.

PROBLEM BREAK 2-3

Some people think the push of the escaping gases *on the air outside* is what moves a rocket along. This idea suggests that the more air outside and behind the rocket, the more force (thrust) it will have. See for yourself whether this is the case.



ACTIVITY 2-11. Open the clamp all the way and note the force on the blade. With the jet running, raise the full jar of water under the jet. The discharge should be under the surface of the water. Note the force under this condition. Do this several times until you are sure that you see what happens. Be sure that the blade and tip are not touching the jar.

GET IT READY NOW FOR CHAPTER 3

You will need smooth, level surfaces for the activities with the water-drop cart. These must be at least 2 metres long. They could be tables, areas of the floor, or a platform.

☐ **2-22.** What force did you measure with the jet discharging under water?

☐ **2-23.** How did this force compare with the force measured with the jet out of the water?

2-24. The answers should be interesting. If the students found that the force with the jet under water was less, the most common answer will be, "The water in the jar kept the water from coming out of the jet as fast."

☐ **2-24.** How would you explain the difference in force if there was any?

☐ **2-25.** Do the results of this activity agree with the ideas of those people mentioned?

Before going on, do Self-Evaluation 2 in your Record Book.

EQUIPMENT LIST

1 force measurer, both blades
1 force-measurer card, calibrated
3 paper-clip hooks
4 sinkers

PURPOSE

To afford practice in measuring forces in standard units.

Excursion 2-1

Newtons of Force

MAJOR POINTS

1. From identifications of the different force variables (gravity, compression, elasticity), it is concluded that
   a the result of a force is most noticeable when that force is unbalanced, and
   b unbalanced forces cause changes in the shape and motion of elastic bodies.
2. Analysis of equipment design (force measurer) leads to the conclusion that the sensitivity (range) of a force measurer varies with the elasticity of the blade.
3. The operational definition statement for force "A force causes changes in the shape or motion of an object and can be measured by the amount of change it causes," really applies to an unbalanced force.
4. Newton's laws of inertia, acceleration, and reaction are stated.

This is a remedial-review excursion for students who have not used, or have forgotten how to use, a force measurer and units of force.

Look around you. Everything that you can see has a force acting on it. The chair, the desk, your books, even you are being pulled toward the center of the earth.

Why don't you notice this pull? Well, it's simply because this pull of gravity is balanced by other forces. Your desk pushes up on this book. The floor pushes up on your chair, on your desk, and on the people in your room. As long as the force on an object is balanced by an equal and opposite force, the object remains in its present state of motion. Moving objects continue to move; stationary objects remain stationary.

☐**1.** What happens to an object when an unbalanced force (a force that is not balanced by another force in the opposite direction) acts on it?

Let's find out. Suppose one of your classmates drops a rubber ball, as shown in Figure 1.

☐**2.** What happens to the ball?

☐**3.** As the ball falls toward the floor, what happens to its speed?

☐**4.** When the ball hits the solid floor, what happens to it?

Figure 1

If you had a high-speed camera focused on the ball as it hit the floor, you could see, in detail, what happens. Figure 2 diagrams this.

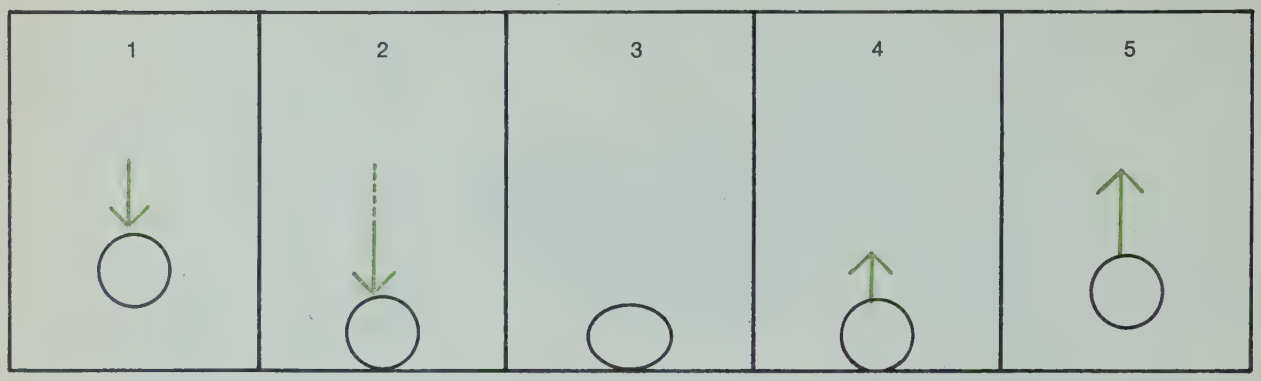


Figure 2

1. The ball approaches the floor.
2. The ball touches the floor.
3. The solid floor stops the bottom of the ball. The rest of the ball continues moving, and the ball is compressed, or flattened.
4. The elastic ball material pushes on the floor and on itself. Then it begins to regain its shape.
5. And it bounces upward.

☐**5.** How must the upward elastic force on the ball compare with the force of gravity to make the ball bounce?

5. It must be greater. (In other words, there must be an unbalanced force upward for the ball to bounce. This is an important point in rocketry. If the upward force on a rocket is not greater than the downward force of gravity, the rocket will just sit on the pad.)

☐**6.** As the ball continues upward from the floor, what happens to its speed?

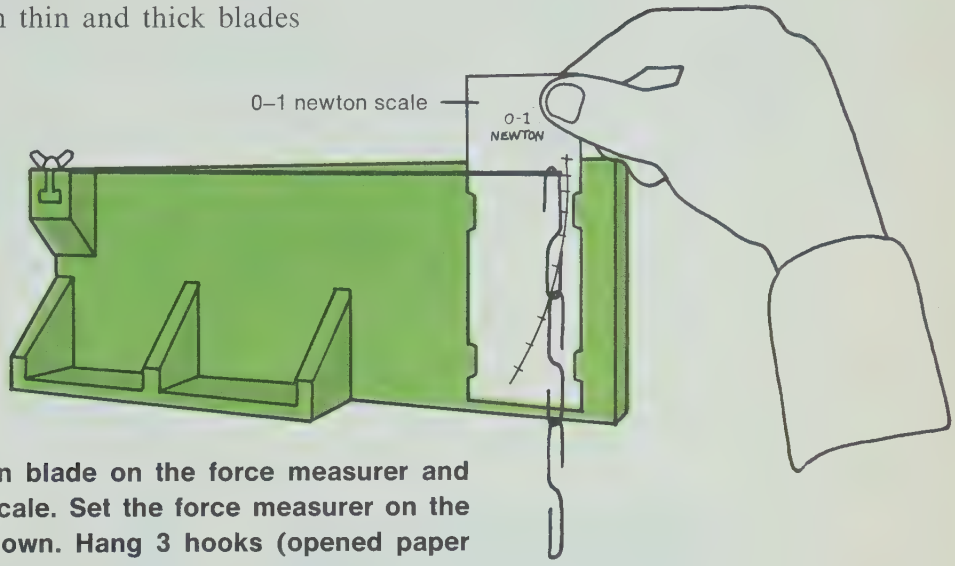
This could all be summed up by saying, "An unbalanced force on an object causes a change in its motion." But in frame 3 of Figure 2, you see another effect of an unbalanced force. A falling ball, stopped by the floor, changes its shape. In this case, one part of an elastic object can't move, and the unbalanced force of motion causes the ball to change shape (compress, then expand).

The change in motion or change in shape of an object when a force acts on it is part of the operational definition of a force. If you don't understand what an operational definition is, do **Resource 17,** "Operational Definitions."

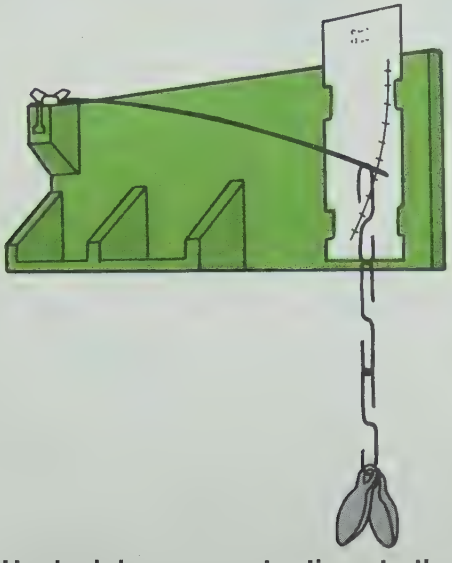
RESOURCE

Measuring force by measuring changes in motion is usually difficult to do. Measuring the change in shape of an elastic object turns out to be an easier way of measuring force. Perhaps you have used a force measurer before and have seen its blade bend under a force. It's worth looking at again. You will need the following equipment:

1 force measurer, with thin and thick blades
4 sinkers
3 paper-clip hooks
1 0–1 newton scale
1 0–10 newtons scale



ACTIVITY 1. Put the thin blade on the force measurer and insert the 0–1 newton scale. Set the force measurer on the edge of the table as shown. Hang 3 hooks (opened paper clips) onto the blade. Zero the scale by moving the card until the zero mark lines up with the blade tip.



ACTIVITY 2. Hook sinkers, one at a time, to the bottom clip, reading the force after each sinker is added. Keep adding sinkers until the force is about 1 newton.

Commercially supplied sinkers vary somewhat in weight. Theoretically, a one-ounce sinker has a mass of 28.35 grams and weighs about 0.28 newton at sea level. Thus, if the sinkers had all the material in them that they should have, 4 would weigh 1.12 newtons. However, in finding the mass of 100 "1-ounce" sinkers selected randomly, a variation was noted from about 24 grams to 29 grams, with the average mass of 26.4 grams. Within the limits of the force measurer's accuracy, 4 sinkers should weigh close enough to 1 newton.

7. About 0.25 newton

☐**7.** About how much force in newtons did each sinker exert?

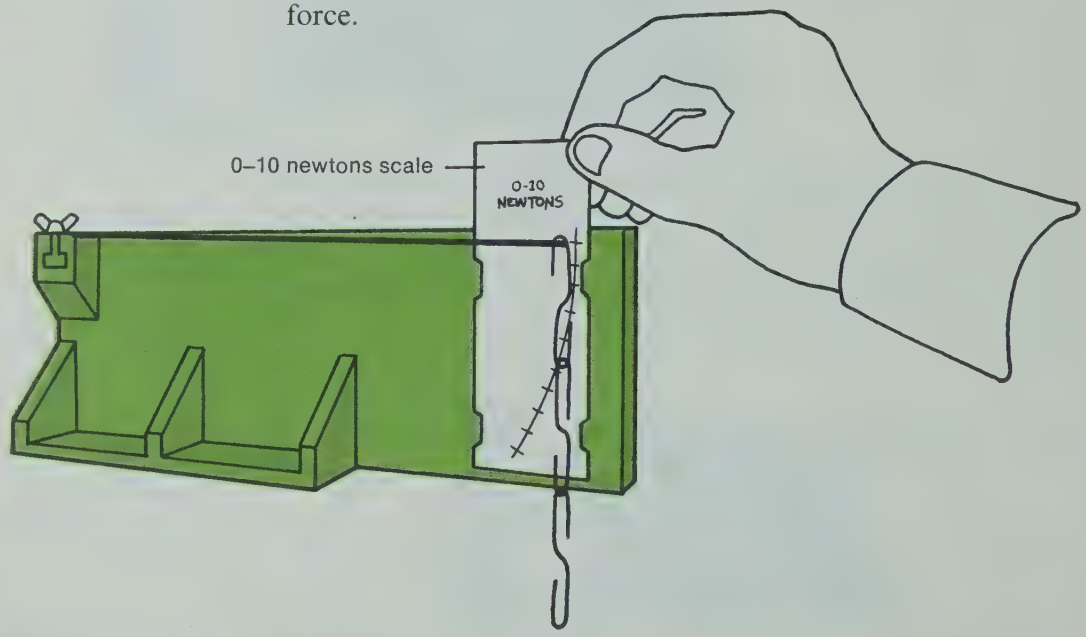
8. 4

☐**8.** How many sinkers did it take to exert a force of about 1 newton?

A better student may ask, "In terms of weight in pounds, how big is a newton?" Simple conversions from one to the other (English to metric or vice versa) are as follows:
1 newton = 0.225 pound
1 pound = 4.45 newtons
In other words, a newton of force is a little under $\frac{1}{4}$ pound; a pound of force is almost $4\frac{1}{2}$ newtons.

The unit of force the newton (abbreviated N) was named after the scientist Sir Isaac Newton, who stated the laws of motion 300 years ago. It is the unit of force that will be used throughout this course.

Notice that the force measurer behaved according to the idea of an unbalanced force causing motion. With no sinkers on the blade, the reading was zero. When sinkers were added, the blade moved down. Being elastic and fastened at one end, the blade changed shape as a result of the added force.



ACTIVITY 3. Remove the sinkers and hooks from the thin force-measurer blade. Replace the blade with the thick one. Insert the 0–10 newtons scale. Hang the three hooks on the blade and zero the scale. Then put the same number of sinkers on the bottom hook that you found exerted a force of 1 newton. (See your answer to question 8.)

☐**9.** What does the force measurer read?

☐**10.** How many times more force can the thick blade measure than the thin blade can?

Suppose you wanted to use the force measurer for forces one tenth as great as those measured with the thin blade.

☐**11.** What would you have to do?

11. Use a thinner blade. Actually, that is the problem with the rocket test stand in Chapter 2, but instead of using a thinner blade, a different material (plastic) is used.

☐**12.** Describe how you would use the force measurer to measure upward forces.

12. Descriptions will vary. Some students may say that you should turn the force measurer over, which could be done, but this is not necessary, because a blade can measure forces in either direction as long as there is a readable scale attached.

Well, now you know something about forces and what the force unit is. Perhaps you would also like to know a bit more about the laws of force and motion that Newton stated. In simple terms, here is what he said.

1. If all the forces acting on an object are in balance, the object will remain as it is.
2. If an unbalanced force acts on an object, the motion of the object will change. The amount that the motion changes will depend upon how much force acts and how massive the body is.
3. If one object exerts a force on a second object to change its motion, then the second object exerts an equal and opposite force on the first object to change its motion.

The three laws stated here have been paraphrased. In order, they could be thought of as laws of inertia, acceleration, and reaction. A further discussion of Newton's laws can be found in the Introduction of this module.

You have already had some experience with the first two statements. Your force measurer should have helped you see how they worked. The third one, called the *reaction principle,* is one of the main ideas in rockets. The air and water inside the water rocket exert a force on the rocket's inner walls. At the same time, these walls exert an equal force on the water and air. If for some reason the balance is lost, a change in motion or shape or both will occur.

☐**13.** If the nozzle is opened, will the forces be in balance?

50
100
150
200
250
0 1 2 3 4 5
8 9 10

Filmstrip Key

Technique
Accelerating Water Clock

How Much Is Needed?

CHAPTER EMPHASIS

Students find the amount of force, or thrust, that is needed to lift a rocket and speed it on its way. They then investigate the effect of decreasing mass on change in speed of an object when the force on the object is held constant.

3

MAJOR POINTS

1. Motion is the result of an unbalanced force: e.g., a force of just slightly more than the weight of the water rocket is needed to lift the rocket.
2. The relationship of speed, mass, and force can be determined using a force measurer and water-clock cart.
3. Varying one variable at a time shows these results: (a) if force is constant, change in speed varies inversely with mass; (b) if mass is constant, change in speed (acceleration) varies directly with force; (c) if force and mass both are constant, change in speed varies directly with time
4. Change in speed of a moving object can be measured indirectly by measuring distance moved during equal time intervals.

EQUIPMENT LIST

Per student-team

1 force measurer, both blades
1 calibrated card, both scales
1 water rocket with funnel
1 pail of water
4 paper-clip hooks
1 100-ml calibrated beaker
1 metrestick
1 baby-food jar
3 0.5-kg masses
2 metres of string
Tape
Paper towels
1 cart, with water clock

Excursions 3-1 and 3-2 are keyed to this chapter.

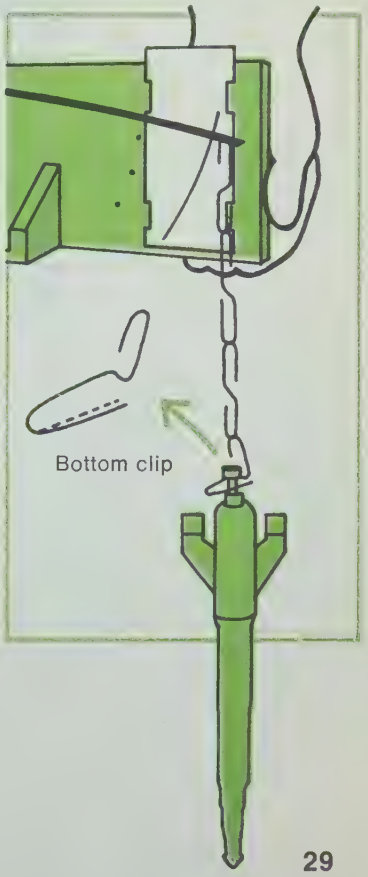
By now you have some idea of what gives the force, or thrust, that puts a rocket into space. To get your water rocket launched, you put water inside it. The pump added air under pressure. The volume of water and the speed with which it was forced out gave the thrust you needed.

But how much force is necessary to get the rocket to rise? Let's see if you can find out the answer by making a few measurements. Select two partners and get the following equipment for your team:

1 force measurer, with thin and thick blades
2 cards with premarked scales (0–1 N and 0–10 N) (Remember, the N stands for newtons of force.)
1 dry water rocket
1 funnel
1 pail of water
4 paper-clip hooks
1 100-ml beaker or other container that can be used to measure water in ml

5. Applying techniques of experimenting is an important factor in successful investigating, e.g., averaging trials and zeroing scales according to physical position of measuring device.

6. It is often desirable to study the variables involved in a complex situation by studying a similar situation, involving the same variables, in which the variables being investigated can be more easily manipulated and measured. An example of this is the use of the water-clock cart to investigate the variables affecting the water rocket.



ACTIVITY 3-1. Use the thin blade for now. Open the 4 paper clips and link them together as shown. Zero the force measurer with only the clips in place. Bend the large end of the bottom clip as shown, and fit it over the flange of the rocket. Support the empty rocket in an upside-down hanging position. *Did you remember to use your 0–1 newton scale?*

3-1. About 0.36 newton

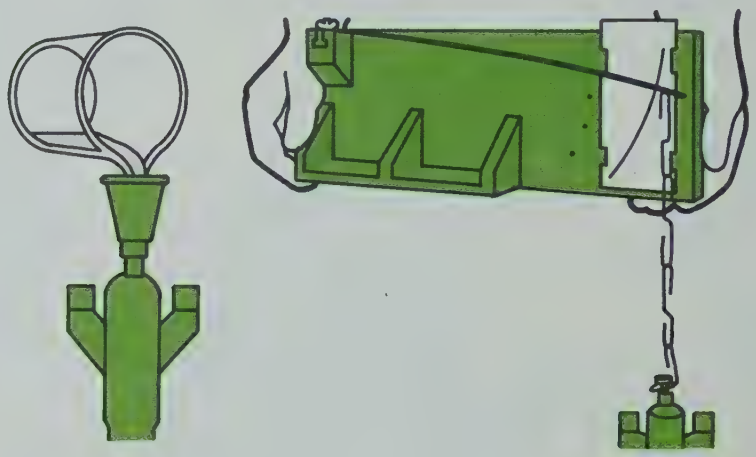
☐**3-1.** What is the force-measurer reading in newtons?

You have measured the force of gravity on the mass of the empty rocket. This measure is the rocket's empty weight. You know that the rocket must have water in it for best performance. You can think of the water as the rocket fuel. You used a certain number of ml of water to push the rocket to its greatest height. Refer back to Problem Break 1-1.

3-2. Answers will vary because of experimental findings in Chapter 1, but it probably will be around 75 ml.

☐**3-2.** How many ml of water did you use to send the rocket to its greatest height?

The water added to the rocket has mass. Air was also added to make the rocket go. It, too, has mass, but its mass is small compared with the mass of the water. Therefore the increase in the rocket's mass is due primarily to the added water. You can find out how much mass was added by using your force measurer.



There may be students in your classes who remember that water has a mass of 1 gram per millilitre. Therefore, once they have weighed the empty rocket (question 3-1 above), they can simply add the weight (in newtons, not grams) of the particular amount of water from question 3-2. Roughly, a millilitre of water weighs about 0.01 newton. More accurately, the mass in kilograms multiplied by 9.8 gives the weight in newtons at sea level on the earth. Thus, 75 ml weigh, by the rough method, 0.75 newton, more accurately 0.735 N.

If you have a broken rocket, it can work fine for these activities.

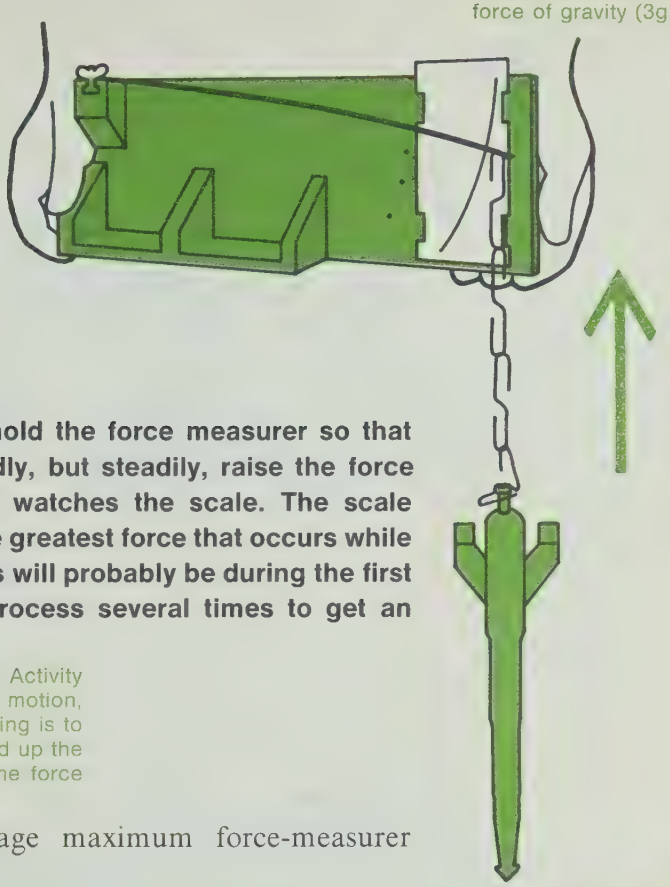
ACTIVITY 3-2. Use the funnel and calibrated container. Add to your rocket the number of ml of water given in your answer to question 3-2. Weigh the fueled rocket again as you did in Activity 3-1. You may have to use the thick blade and the 0–10 newtons scale.

☐**3-3.** What is the weight in newtons of the fueled rocket?

This total weight is the force of gravity acting on the rocket and its contents. It is the force that must be overcome before the rocket will rise.

☐**3-4.** If the rocket is to rise, and not just hang in space, what must happen?

Remember, this activity is done with a fueled rocket (water added). Probably students will note a force-measurer reading in rapid lift of 3 to 4 newtons, which is about 3 times the force of gravity (3g's).



ACTIVITY 3-3. Once more, hold the force measurer so that the rocket hangs free. Rapidly, but steadily, raise the force measurer while one partner watches the scale. The scale observer should watch for the greatest force that occurs while the rocket is being lifted. This will probably be during the first second of lift. Repeat the process several times to get an average.

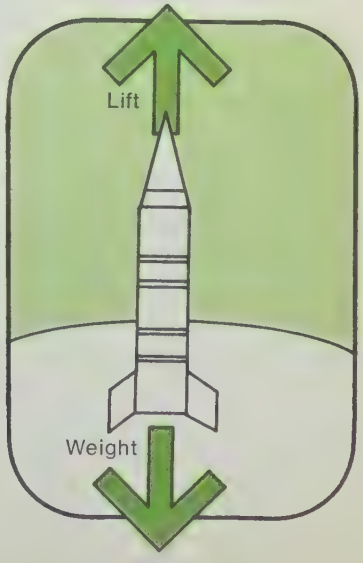
Reading the force-measurer scale in Activity 3-3 may be difficult because of rapid motion, but it can be done. The important thing is to see that the force necessary to speed up the rocket is appreciably greater than the force of gravity.

☐**3-5.** What was the average maximum force-measurer reading on rapid lift?

☐**3-6.** How does the rapid-lift force compare with the force of gravity on the fueled rocket? (Look back at your answer to question 3-3.)

The additional force needed to give the rocket motion shouldn't have surprised you. An unbalanced force must be exerted on an object at rest to get it moving.

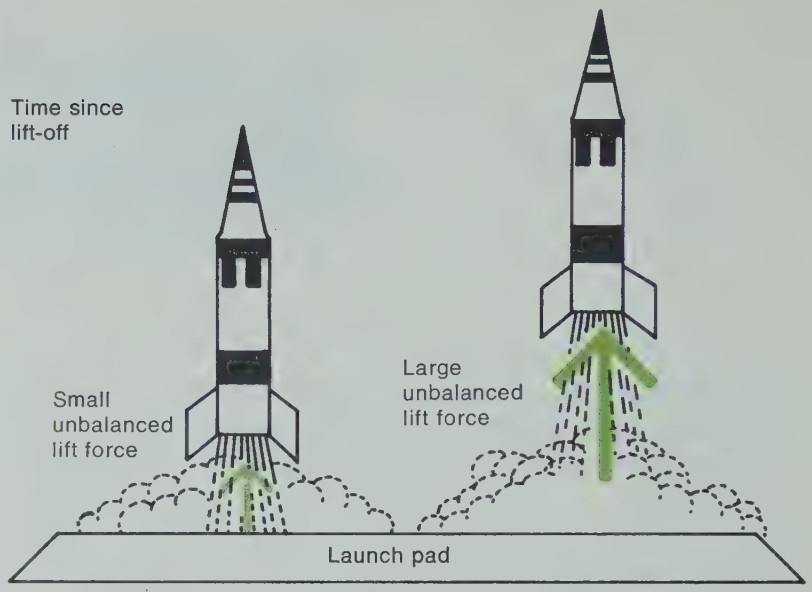
☐**3-7.** Suppose an upward force that is just equal to the weight of the rocket and its contents is applied. Would the rocket move upward? Explain your answer.



Recall when you lifted your water rocket with the force measurer. You probably noticed that the amount of an unbalanced force measured depended on how fast you lifted.

3-7. No. There must be an unbalanced force acting upward on the rocket. (The key word in the question is *equal*. It can't be equal and unbalanced at the same time.)

To say it another way, the greater the unbalanced lift force, the faster the lift speed. Thus, the farther the rocket will have gone since lift-off. Figure 3-1 illustrates this.



It might be interesting to know that the unbalanced force on the water rocket at lift-off is in the neighborhood of 5 newtons. With a mass of a little more than 0.1 kg, this force causes a rather rapid change of speed (acceleration) of more than 50 metres per second every second. This force, and therefore this acceleration, is of very short duration. Not only does the available water rapidly exhaust, but the air pressure, which controls the speed of exhausting water, drops very rapidly also. The rocket probably has this maximum force for a small fraction of a second, but it is long enough to send the rocket rapidly on its way.

Figure 3-1

Another important thing is happening to your water rocket as it lifts off from the launch pad. It is related to the mass of the rocket and its contents.

☐**3-8.** Does the total mass of the rocket plus its contents remain constant throughout its flight? Explain your answer.

You should investigate the effect this change in mass of the rocket has on its performance. You'll need to work with 3 or 4 other classmates who are at this point in the text. Your team will need the following materials:

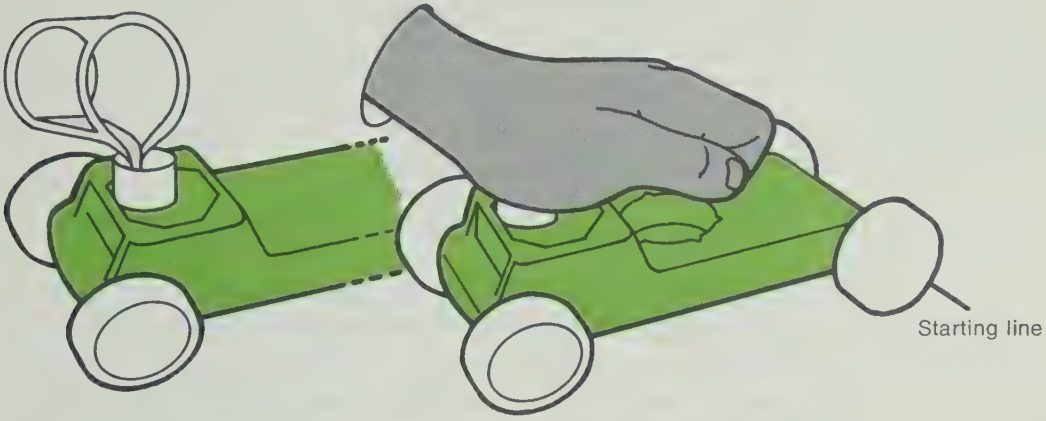
The equipment list includes paper towels. The water-clock carts can be quite messy. Make towels available.

1 cart, with water clock
1 jar for water
1 metrestick
paper towels

Look for a flat, fairly smooth surface at least 2 metres long. If this amount of space is available on a table, use it. Otherwise, you will need to do the activity on the floor.

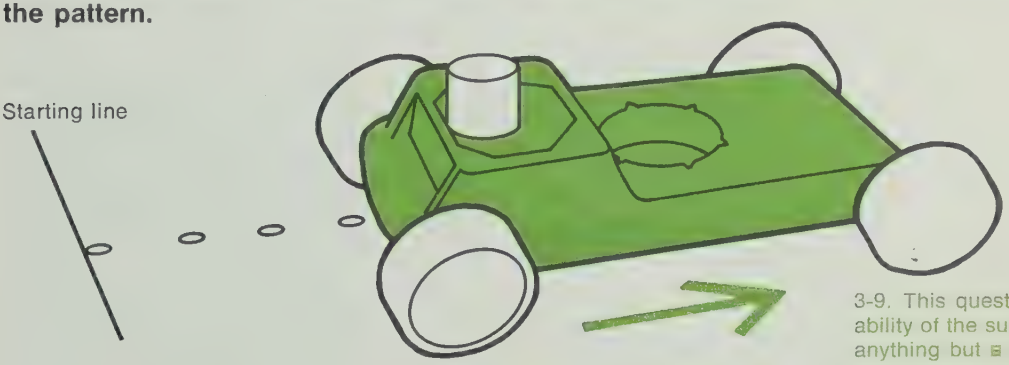
First, you need to use the water-clock cart to see what can be measured with it.

ACTIVITY 3-4. Place the water clock in position on the cart and fill it completely with water. Place the front of the cart on a line you have marked on the table or floor. Then push down gently with your palm to start the water dripping. You can stop the water clock from dripping by putting a moistened square of thin cardboard on top. When dripping is desired, simply remove the square.



ACTIVITY 3-5. Now give the cart a gentle push until its back wheels reach the line. Then stop pushing and let it coast. Look at the pattern of drops it leaves behind. Don't disturb the pattern.

If you use the cart on the floor, you can use food coloring to color the water so that the drops will show up better.



☐**3-9.** Did the speed of your cart in Activity 3-5 increase, decrease, or stay the same after you stopped pushing?

3-9. This question can be a test of the suitability of the surface. If the dot pattern shows anything but a slow, steady decrease in distance between drops, the surface is not level.

You may need help with question 3-9. Each drop falling from the cart takes the same amount of time to form and reach the surface. Thus, the distance between drops on the surface can tell you whether the cart's speed was unchanging, increasing, or decreasing. It can also tell you the amount of change between each time interval.

In Figure 3-2, three water-drop tracks are shown.

There will be students who have never used the water-drop cart before, and you may have to spend a little time in orientation. The statement is made here that the time interval between drops is constant. Although the time interval is not used in the activities, you may want to have student teams count the number of drops in several 20-second intervals to prove to themselves that the rate remains the same. Be sure the water clock is full for each trial.

The surface on which the drops fall should be smooth and nonabsorbent. On untreated wood or pressboard, for example, the drops will spread and sink in quickly, making it difficult to take measurements. A thin application of furniture wax or car polish will help.

☐**3-10.** Which track in Figure 3-2 indicates no change in cart speed? Which track indicates an increase in speed? Which track indicates a decrease in speed?

Depending on the distance available for the cart to coast and the speed at which it was pushed, there may be more than or less than seven intervals to measure. The actual number is not important as long as the pattern is discernible.

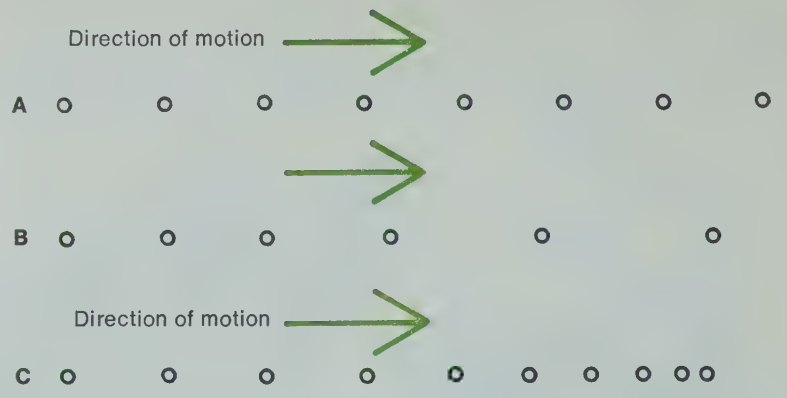


Figure 3-2

ACTIVITY 3-6. Measure the distance between each pair of drops from Activity 3-5. Start with the drop nearest to the point where you stopped pushing the cart. Make your measurements to the center of the drops. List the distances in Table 3-1 of your Record Book.

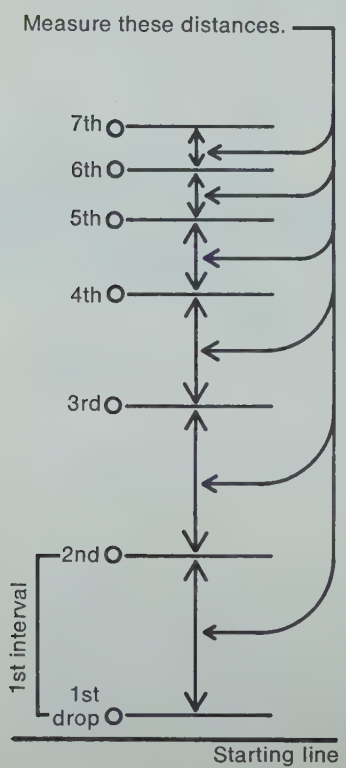


Table 3-1

Interval	Distance traveled (in cm)
1st	
2nd	
3rd	
4th	
5th	
6th	
7th	

The shorter distances indicate that the cart slowed down after you stopped pushing it. That's no surprise, of course. What good is all this then?

Your water-clock cart can be used to identify changes in speed. All you have to do is look for changes in the distance between drops.

Students may need help in seeing that a distance measurement between drops can be a measure of the speed of the cart. Remind them that speed equals distance traveled per unit of time, and the water-drop interval is the constant unit of time being used. If there are any who are curious enough to want to go further and find the actual numerical speed in cm/second, the following procedure may help.

A timing of the drop rate of the water clock will probably give some figure like 50 drops in 20 seconds. This means that there is a time interval per drop of 20 sec/50 drops, or 0.4 sec per drop. Say the cart moved 5 cm between two drops. The speed for that interval would be 5 cm/0.4 sec, or 12.5 cm/sec.

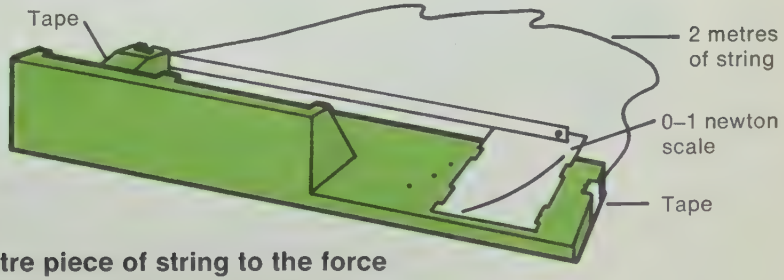
☐ **3-11.** What must have happened to the speed of the cart if (**a**) the distance between drops increases? (**b**) the distance between drops decreases? (**c**) the distance between drops stays the same?

Now you can find out how speed, mass, and force are related. To do this, your team will continue working with the cart. You will also need:

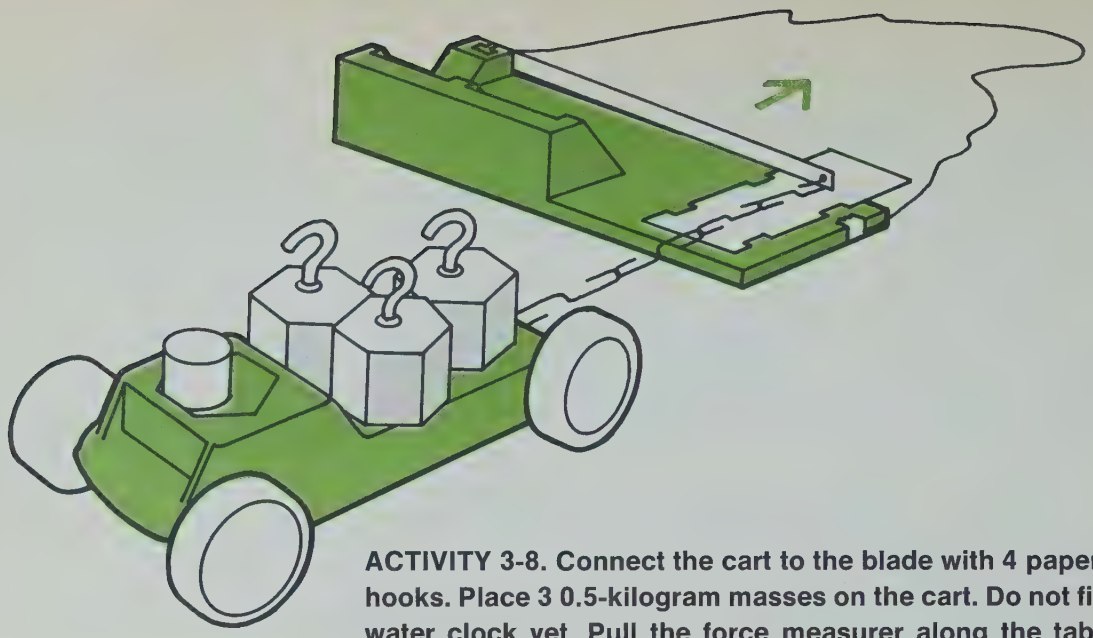
1 force measurer, with thin blade and 0–1 newton scale
4 paper-clip hooks
1 piece of string, 2 metres long
3 0.5-kilogram masses
Tape

The two questions you want to investigate are these: When a constant unbalanced force is applied to an object, how will the object's speed change? and What effect will result if the object also loses some of its mass?

You can use the force measurer to apply a constant force on the cart. And you can vary the mass of the cart by loading it with 0.5-kilogram masses and then removing them one at a time. The cart would then be like the rocket that moves upward under a constant force while its mass gets less and less as its fuel is used up. Try the cart experiment and see what happens.



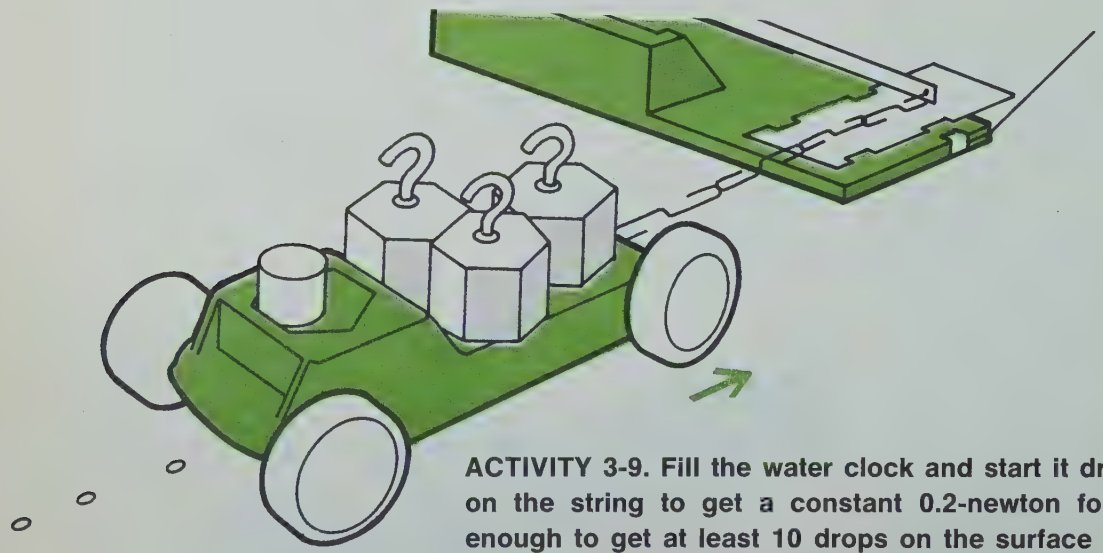
ACTIVITY 3-7. Fasten the 2-metre piece of string to the force measurer with tape as shown. Then lay the force measurer on its back. Zero the force measurer while it is in this position. Have the thin blade in place and use the 0–1 newton scale.



A great deal of the success in keeping a constant 0.2-newton force on the force measurer is dependent on the smoothness of the surface. On a rough surface, the measurer will jump so much that it is next to impossible to keep a constant force.

ACTIVITY 3-8. Connect the cart to the blade with 4 paper-clip hooks. Place 3 0.5-kilogram masses on the cart. Do not fill the water clock yet. Pull the force measurer along the table or floor. Try to keep the force on the cart constant at 0.2 newton.

You will need to practice to keep the force constant at 0.2 newton. Make several runs until you can do it. The force may vary a little above or below the correct amount. But the blade should stay fairly close to the 0.2 mark.



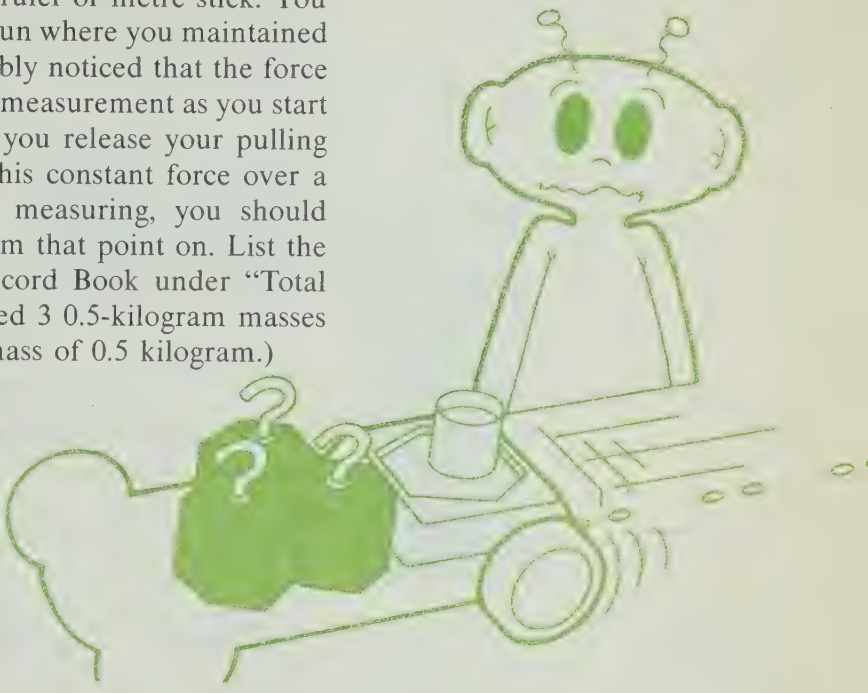
ACTIVITY 3-9. Fill the water clock and start it dripping. Pull on the string to get a constant 0.2-newton force. Go far enough to get at least 10 drops on the surface of the table or floor. Examine the pattern of drops.

Caution *If you are working on a table, be sure to have one of your partners stop the apparatus at the edge.*

☐**3-12.** With a constant force applied, did the cart gain speed, lose speed, or travel at a constant speed?

3-12. It must gain speed with a constant unbalanced force.

Using the same method you used in Activity 3-6, measure the distance between drops with a ruler or metre stick. You should measure that section of the run where you maintained the force at 0.2 newton. You probably noticed that the force measurer tends to jump to a higher measurement as you start the pull. Then it bounces back as you release your pulling force. It will take practice to get this constant force over a 2-metre run. Wherever you start measuring, you should measure each distance in order from that point on. List the distances in Table 3-2 in your Record Book under "Total mass: 2.0 kg." (Remember, you used 3 0.5-kilogram masses on the cart. The cart itself has a mass of 0.5 kilogram.)

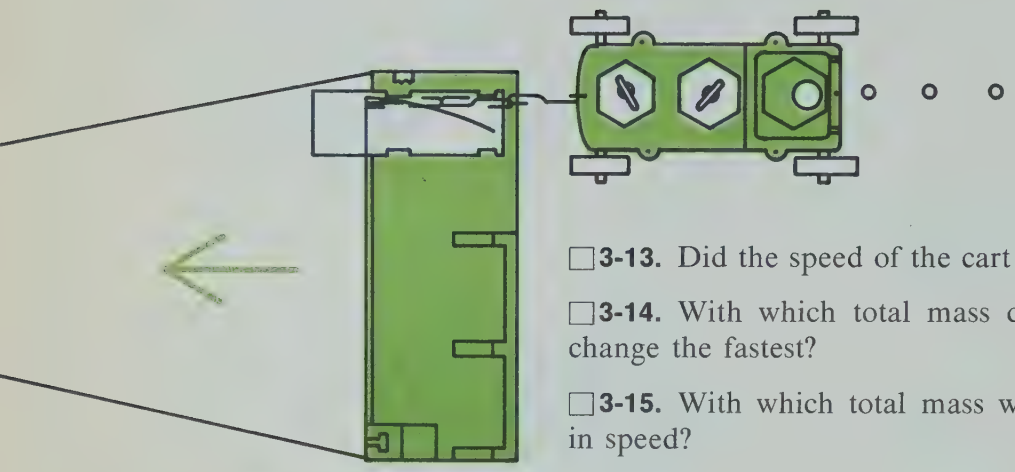


In completing Table 3-2 with successively decreasing mass of the cart, the change in speed will get progressively larger. For instance, an unbalanced force of 0.2 newton exerted on a mass of 2.0 kg will theoretically change the speed of the cart by 10 cm/sec every second. But with the same force acting on a cart whose total mass is 0.5 kg (just the cart alone), the speed will theoretically change 40 cm/sec every second. With this larger change in speed, the student really has to move to keep the force constant at 0.2 newton.

Table 3-2

	Distance (in centimetres)			
Time interval	Total mass: 2.0 kg	Total mass: 1.5 kg	Total mass: 1.0 kg	Total mass: 0.5 kg
1st				
2nd				
3rd				
4th				
5th				
6th				

ACTIVITY 3-10. Remove one mass from the cart and repeat the pulling activity. Be sure the water clock is operating and the force is kept constant at 0.2 newton. Record the distance measurements in Table 3-2 under "Total mass: 1.5 kg." Then repeat the activity with one mass on the cart, and again with no mass on the cart. Record the measurements in Table 3-2. During each run, keep the force as close as you can to 0.2 newton.



☐**3-13.** Did the speed of the cart increase during each run?

☐**3-14.** With which total mass did the speed of the cart change the fastest?

☐**3-15.** With which total mass was there the least change in speed?

A constant unbalanced force on a body will cause its speed of motion to increase. A greater increase will occur if the mass of the body also decreases. At this point, look at what you have found out and see how it applies to the rocket launch. The following list may help you:

1. Some combination of water and air pressure gives the best rocket performance.
2. The speed of water flow out of the rocket produces a forward force, or thrust, on the rocket.
3. This unbalanced force in the rocket chamber pushes the rocket forward.
4. The amount of force needed to get the rocket off the ground is any amount that is greater than the weight of the loaded rocket.
5. With a constant unbalanced force, the speed of the rocket continues to increase.
6. The greater the unbalanced force, the faster the speed increases.
7. The loss of mass from the rocket causes its speed to increase even faster.

The eight summary statements here and on the next page are a good review for all the work to this point. They could be the basis for test questions or small-group discussions. Equally important, these statements mark the transition point in the student's study from water rockets, balloons, carts, and force measurers to the real world of operational rockets of the space program.

As background information, you may be interested in the following data on the Saturn V that launches the moon shots.

1. Total weight of spacecraft at lift-off—28 500 000 newtons
2. Weight of fuel and oxygen, first stage—21 000 000 newtons
3. Rate at which mass of fuel is thrown out—13 300 kg/sec
4. Speed at which mass of fuel is thrown out—2550 m/sec
5. Total force or thrust at lift-off—33 900 000 newtons
6. Total unbalanced force at lift-off (#5 minus #1)—5 400 000 newtons
7. Mass of the total spacecraft at lift-off—about 2 900 000 kg

8. Change in speed (acceleration) at takeoff—about 1.9 m/sec every sec (You can find this by dividing the total unbalanced force in #6 by the total mass in #7.)

If you were a careful observer, you may have found out another thing. When you fired the water rocket, the water was forced out rapidly. In a very short time, there is no more water to apply an upward force. The rocket then slows to a stop at its maximum height and returns to the ground.

Apparently the length of time that a force is applied has an effect on the speed that a rocket attains. You could add that point to the list.

8. The longer an unbalanced force is applied, the more the rocket will speed up.

☐**3-16.** Suppose you could continue to apply an unbalanced upward force on the rocket for a longer time. What would happen to it?

☐**3-17.** When the rocket starts to fall back to the earth, what force is then unbalanced?

You used water and air as the fuel to make your rocket leave the ground. The Saturn rocket uses a kerosinelike fuel mixed with oxygen. This mixture is burned in the combustion chamber. The hot gas produced exerts pressure and pushes the rocket on its journey. This hot gas rushes out the nozzle of the engine. It rushes out in much the same way that the gas (air) shot out of the balloon in the activity you did earlier. But there is a lot of fuel being burned, so it continues to rush out for a longer time than the gas from the balloon.

Perhaps you would like to know more about the way fuel and oxygen react in a real rocket. Or you may want to know how the hot gases that are produced push the rocket. If so, do **Excursion 3-1,** "The Big Push."

In addition, there are other factors that affect the speed of a rocket at higher altitudes. You will work with these variables in the next chapter.

After all the fuel is gone, there is good reason for ejecting the first stage on a rocket. Would you like to examine the effect of discarding the first stage and to see why rockets are built in stages? If so, do **Excursion 3-2,** "One Stage at a Time."

Before going on, do Self Evaluation 3 in your Record Book.

It is interesting to note that even though the mass of the spacecraft is decreasing at a rate of 13 300 kg/sec—that's over 13 metric tons per sec—its total mass is so great by comparison that it takes quite a while for the decrease in mass to have much of an effect on change in speed. And with that low change in speed of 1.9 metres per second per second, it is no wonder that the rocket rises so slowly at first. 9. As mentioned here, the little water rocket exhausts its "fuel" quite rapidly. The Saturn V, however, carries such a huge amount of fuel in its first stage, that it supplies the tremendous thrust for a relatively long time. The center engine of the five cuts off at 135 seconds. The other four engines cut off at 162 seconds with some fuel remaining in the tank. By then the spacecraft is well on its way.

Excursion 3-1 is for general interest and extension. It uses no equipment and could be done at home

Excursion 3-2 is a longer-than-usual extension excursion In it the student constructs a reaction cart.

GET IT READY NOW FOR CHAPTER 4

Students use easy-to-assemble ball launchers on the force measurer.

Excursion 3-1
The Big Push

EQUIPMENT

None

PURPOSE

To explain how thrust is developed in a rocket engine by burning fuel.

This is a general-interest and extension excursion that could be done at home. It also reviews the concept of heat as a form of energy.

MAJOR POINT

1. The Matter Model is used to explain
   a. why the energy source of a rocket is the chemical energy stored in the fuels;
   b. why the exhaust of the rocket is different from the fuels and oxygen (because a rearrangement of the reactant particles releases energy and new products); and
   c. why the exhaust gases expand to produce the rocket's thrust.

The method of giving a rocket the necessary push to get it into the sky is based on just one thing—throwing something out the nozzle. The more that is thrown and the faster it is thrown, the greater push there will be.

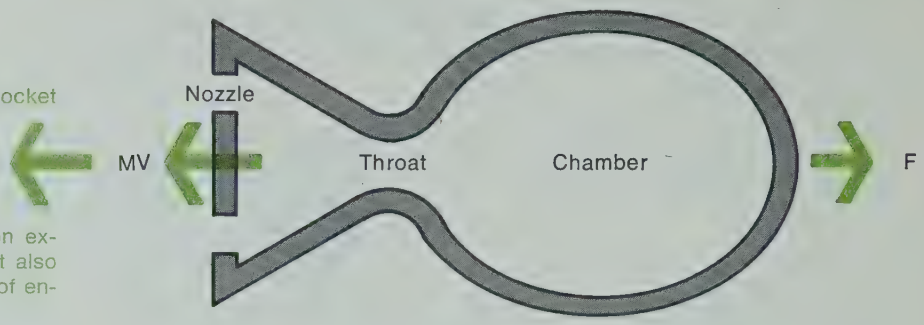


Figure 1

A force is produced in the chamber of the rocket engine. This force pushes material out the nozzle, producing a forward thrust on the rocket. (See Figure 1.) The thrust, F, is equal to the mass, M, thrown out per second multiplied by the speed, V, at which it is thrown.

To get material to shoot out rapidly, a large force must be applied. You probably remember that when a force moves matter, work is done. In order to do work, energy is required.

In the case of your water rocket, air pressure supplied the force necessary to do work. You furnished the energy when you pumped up the rocket. By building up the air pressure, you gave the air a form of potential energy.

☐**1.** What other forms of energy might be used to make matter shoot out of a rocket nozzle?

One of the forms of energy that you listed should have been heat. The matter model talks about the effect of heat on matter. If you are familiar with the matter model, you should be able to answer the following questions. If you have trouble, do **Resource 14,** "The Matter Model."

RESOURCE

☐**2.** What is all matter composed of?

☐**3.** All the different kinds of matter are made up of one or more of the 100 or so kinds of basic particles. What are these particles called?

☐**4.** During a chemical reaction, new combinations of atoms are formed. Where do the atoms in these new combinations come from?

An element is composed of only one kind of atom. Compounds are substances that are composed of two or more kinds of atoms.

☐**5.** Which of the following are formulas representing elements? Which represent compounds? H_2O; Li; $CaCl_2$; HNO_3; N_2; Fe.

☐**6.** Energy changes cause particle rearrangements. Is it also true that particle rearrangements can produce energy changes?

Many rocket fuels are made up of hydrocarbon compounds. These are chemical combinations of the atoms of hydrogen and of carbon. Kerosine, a common rocket fuel, is a mixture of these hydrocarbons. When the molecules of this fuel and pure oxygen react, their particles come together in new ways to form new substances—mostly carbon dioxide (CO_2) and water (H_2O). When this chemical change takes place in the combustion chamber of the rocket, the energy stored in the chemical compounds is released as heat. (See Figure 2.)

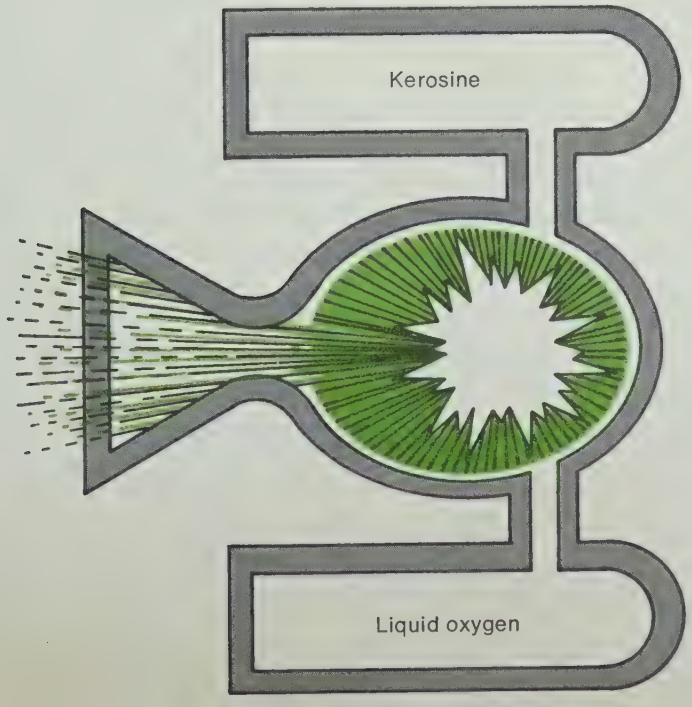


Figure 2

When kerosine is burned with pure oxygen, the temperature in the rocket chamber is about 3000 °C. With hydrogen as the fuel, the temperature is higher still.

You may remember from previous science work or from the matter model how heat affects the particles of matter. If so, you know that as heat is added to a substance, its temperature increases. And as the temperature increases, the particles of the substance vibrate and move around with more and more speed. The final effect is expansion of the substance.

In the rocket engine, a great deal of heat is set free as the fuel burns. The exhaust gases of a rocket may exceed 2500 °C. The particles of reactants and products move very rapidly, and the substance expands. The higher the temperature, the faster the particles move and the more the substances expand.

☐**7.** What must happen when the swiftly moving particles of the expanding gases strike the walls of the engine?

Whatever fuel is used, the same principle of propulsion applies. Tremendous forces are exerted on the combustion chamber walls. That's because of the bombardment of high-speed particles of expanding reactants and products.

On one side of the engine there is no wall to stop the particles. There is only the opening into the engine nozzle. Since there is no wall to stop the particles, they rush out through the nozzle at high speed. They form the long tail of fire behind the rocket. The unbalanced force on the forward end of the combustion chamber pushes the rocket ahead.

Shown in Figure 3 is the launching of Apollo 16. Note the flames and smoke belching from the first stage.

Anything that will burn rapidly can be used as a rocket fuel. One of the most powerful combinations uses no oxygen at all for the reaction. The elements hydrogen and fluorine combine violently. They produce a large amount of heat and give the greatest amount of push per pound of fuel used. Because fluorine is so corrosive and so difficult to handle, however, it has not been used successfully in big rockets.

Steel has a melting point around 1400 °C, so a steel nozzle would melt. Special metals with high melting points, and special cooling systems for the combustion chamber walls need to be employed.

Students have probably seen the streams of water that are flooded onto the launch tower and pad to keep them from being melted and destroyed during a launch.

Figure 3

EQUIPMENT LIST

1 cart, without water clock
1 force measurer, heavy blade
3 large rubberbands
Modeling clay
Tape
Thread
Matches

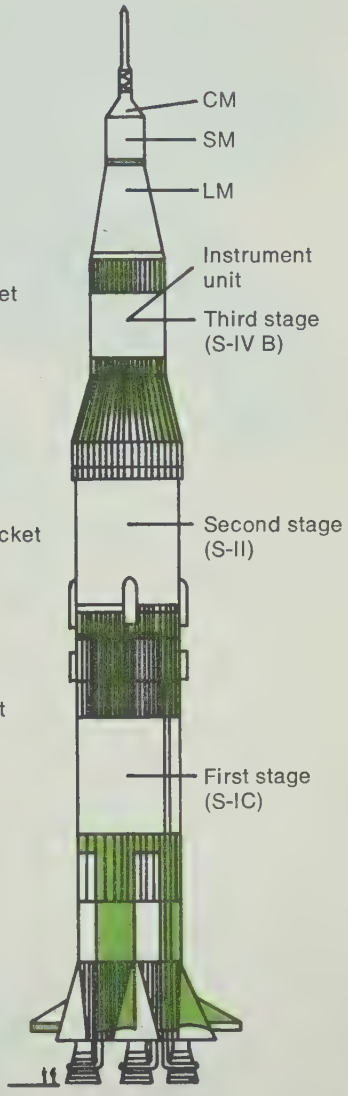
Excursion 3-2
One Stage at a Time

The Apollo spacecraft consists of a command module (CM), a service module (SM), and a lunar module (LM). (See Figure 1.) It has a mass of about 45 000 kg. Three stages of the Saturn V rocket send the Apollo spacecraft on its way.

As you can see, the Apollo spacecraft has a small mass compared with the three stages of the Saturn V rocket. To understand this, you'll do an activity based on an idea that has been around for a long time. Then you can look at how the stages of a rocket operate.

This is an extension excursion.

Figure 1



The third stage of the Saturn V rocket has a mass of almost 120 000 kg.

The second stage of the Saturn V rocket has a mass of more than 480 000 kg.

The first stage of the Saturn V rocket has a mass of about 2 200 000 kg.

MAJOR POINTS

1. Increasing either the speed or the mass of a thrown object produces a greater reaction.
2. For every action there is an equal and opposite reaction.
3. Reaction force (on cart) = mass thrown out/sec × speed at which mass is thrown.
4. If either the mass of exhaust gases thrown out of a rocket or the speed at which it is thrown out is increased, the force pushing the rocket increases.
5. By carrying rocket fuel in stages, the used stage can be discarded after it is spent. Then the mass of that stage doesn't have to be carried along.

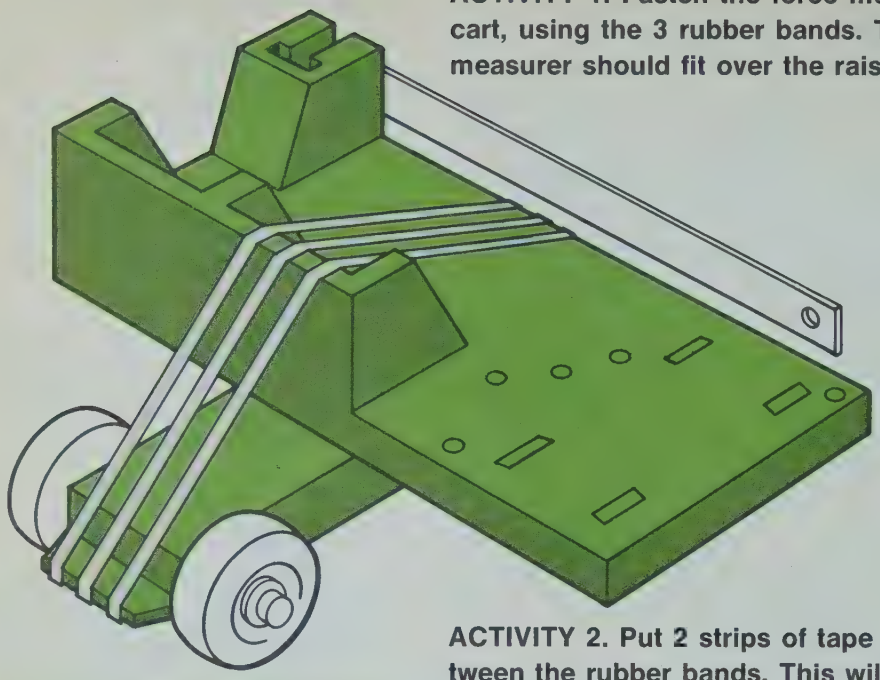
Sir Isaac Newton made the first clear statement of an idea that has been extremely important in science. It is especially useful in rocketry. This idea is called Newton's third law of motion. It says, "To every action there is an equal and opposite reaction." Let's put that in terms that apply to rockets. Suppose you throw something out in one direction from a vehicle. Then there will be a force on the vehicle to push it in the opposite direction. You can investigate this important idea by using the water-clock cart and the force measurer. Here's a list of what you need:

1 cart, without water clock
1 force measurer, heavy blade
3 large rubber bands
Modeling clay
Tape

PURPOSE

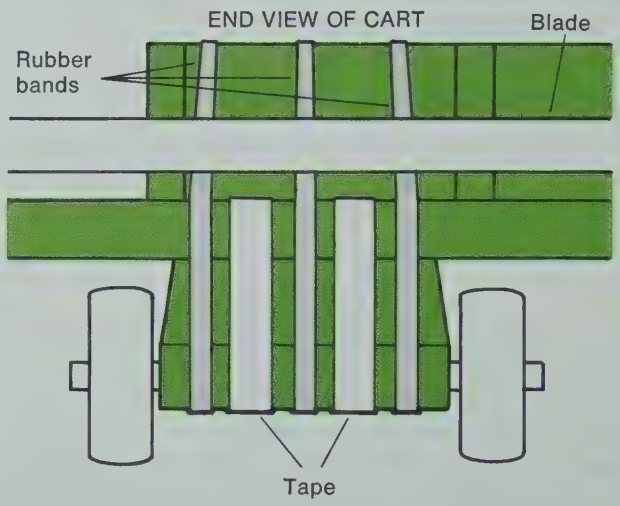
To show the reaction principle with a cart, and apply it to the concept of stages with a Saturn-Apollo spacecraft.

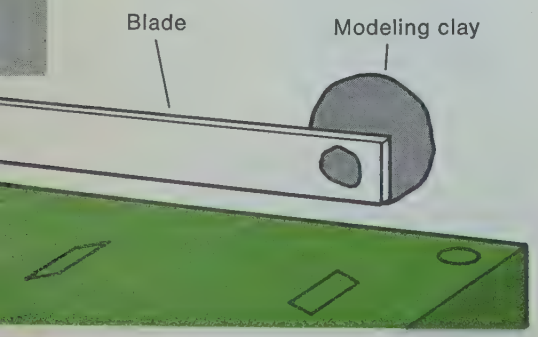
ACTIVITY 1. Fasten the force measurer onto the water-drop cart, using the 3 rubber bands. The center part of the force measurer should fit over the raised part of the cart.



Depending on the number of students at this point, you may want to have one or two cart and force-measurer assemblies ready at all times.

ACTIVITY 2. Put 2 strips of tape on the back of the cart between the rubber bands. This will help hold the force measurer securely to the cart.



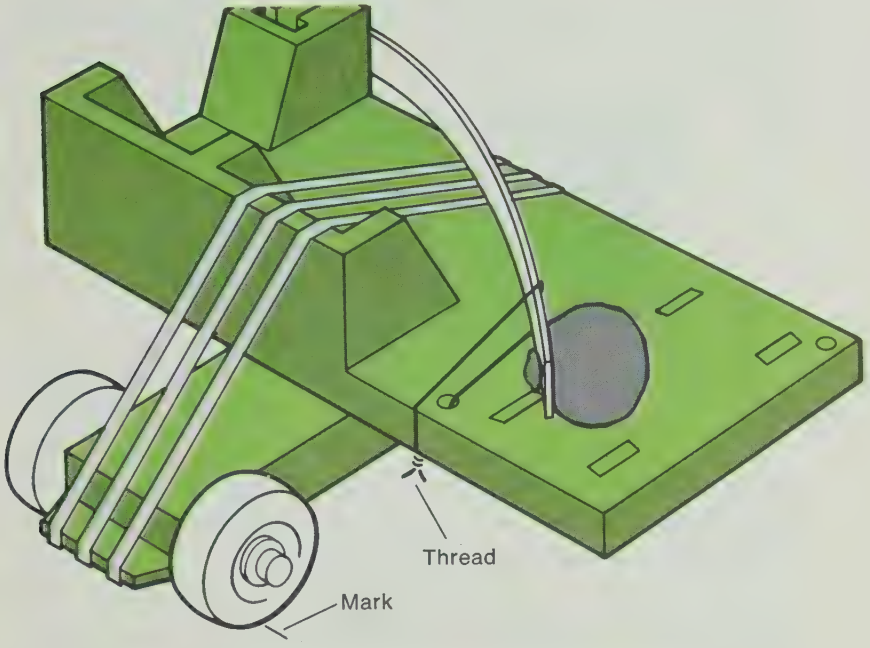


ACTIVITY 3. Form the modeling clay into a ball, about 3 cm in diameter. Push it lightly onto the end of the blade. Have the cart on a smooth, level surface. Be sure that no one is in the way. Then pull the blade back and let it go.

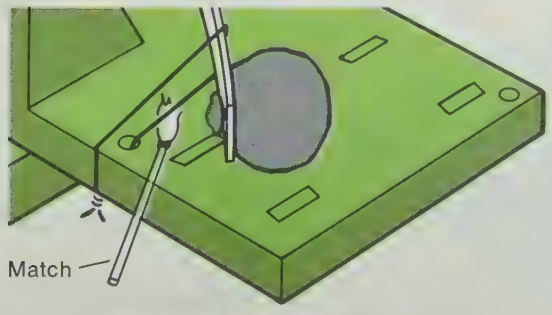
Caution *Use care any time you are launching anything. A projectile could hurt someone.*

You probably couldn't notice a definite effect of throwing the clay ball. Holding the blade back and letting it go kept you from seeing what really happened. But there's a way you can take care of that. You need the following additional things:

Thread
Matches



ACTIVITY 4. Put the cart on a smooth, level surface. Pull the blade back all the way and fasten it there with thread. (You may need help for this.) Then lightly press the modeling clay ball onto the blade. Mark the position of the cart on the surface.



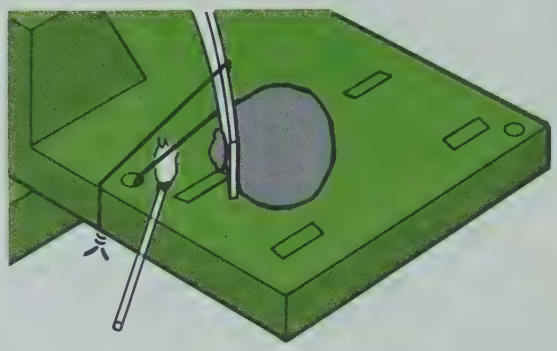
ACTIVITY 5. Light the match. Keep your hands completely clear of the cart as you reach in and burn the thread. Note how far the cart travels.

☐**1.** Describe what happened to the cart when the thread burned.

☐**2.** Which direction did the cart move in relation to the motion of the clay ball?

☐**3.** How far did the cart move?

The farther you pull the blade back, the faster the clay ball travels when released. Therefore you can see what happens when changing the speed at which the clay ball is thrown.

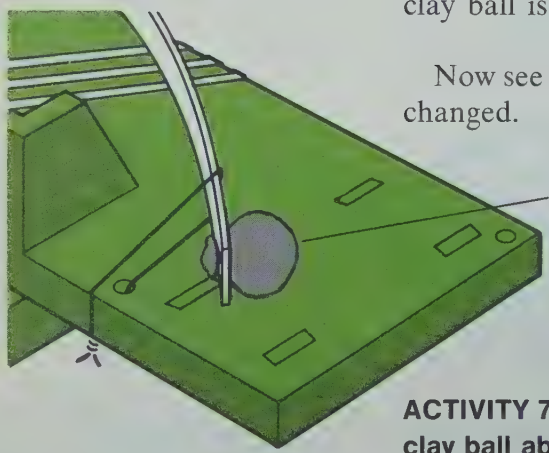


ACTIVITY 6. Pull the blade back half as far and tie it with the thread. Lightly press the clay ball on the blade. Mark the position of the cart. Then burn the thread.

☐**4.** How far did the car move this time?

☐**5.** What is the effect of decreasing the speed at which the clay ball is thrown?

Now see what happens when the amount of mass thrown is changed.



ACTIVITY 7. Pull the blade all the way back and tie it. Make a clay ball about half the mass (half the weight) of the original ball. Lightly press the clay ball on the blade. Mark the position of the cart, and burn the thread.

☐**6.** How far did the cart move?

☐**7.** What is the effect of decreasing the mass of the ball that is thrown?

☐**8.** From your investigation, what two things affect the amount of reaction acting on the cart?

8. a. Amount of mass thrown; b. speed that mass is thrown.

Newton, and many other scientists since his time, have found that throwing mass away from a movable object produces a change in the object's motion. You have been witnessing that effect. In fact, the force on an object is equal to the rate at which mass is thrown away multiplied by the speed at which it is thrown. In other words, force measured in newtons equals mass in kilograms thrown per second times the speed that it is thrown in metres per second.

$$F = (\text{mass/sec})(\text{speed of mass})$$

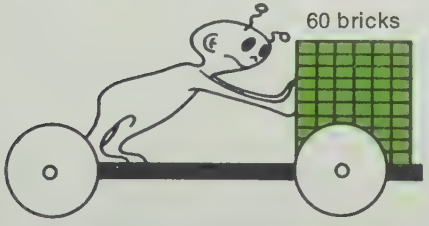
If 1 kg of mass is thrown away every second at a speed of 1 metre per second, the force on the cart is 1 newton.

Now let's get back to those rocket stages. Why are they needed and why is the first one so large?

Suppose you have a cart whose mass is 10 kg, and suppose your mass is 50 kg. With just you sitting on the cart, the total mass is 60 kg. Now suppose you load 60 bricks on the cart. Each brick has a mass of 1 kg. So all of them together would make the total mass of the cart and its contents 120 kg (Figure 2).

Figure 2

Mass of cart	10 kg
Mass of person	50 kg
Mass of bricks	60 kg
Total mass	120 kg



Finally, suppose any number of bricks can be given a speed of 10 metres per second as they are thrown away. The illustrations that follow show the effect this would have on the speed of the cart.

Suppose you threw all the bricks away at the same time (Figure 3). This, of course, would be a huge task.

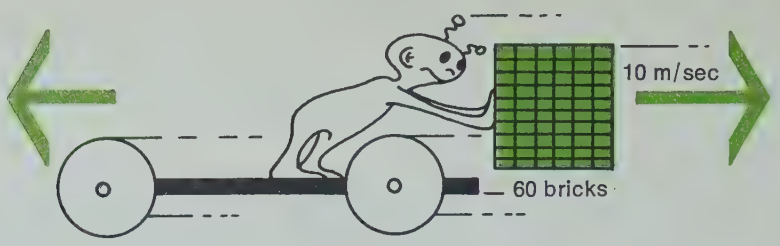


Figure 3

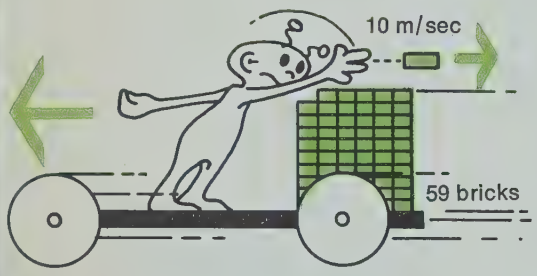
Recall that the force on the cart is equal to the mass thrown away times the speed with which it is thrown. Suppose you threw 60 kg of bricks at 10 m/sec. Then the force on the 60-kg remainder (the cart and you) is $F = 60 \times 10$, or 600 N.

☐**14.** If the cart is at rest when the bricks are thrown, how will the speed of the cart change?

☐**15.** In what direction will the cart move?

14. The speed of the cart will change from zero (at rest) to 10 m/sec. This is an excellent example of action-reaction. With the mass of you and the cart the same as the mass of 60 bricks, whatever happened to the bricks will happen to you and the cart in the opposite direction. From a physics standpoint, this simply means that in closed system, momentum (mass times velocity) is conserved. The mass times the speed in one direction must equal the mass times the speed in the opposite direction.

Figure 4

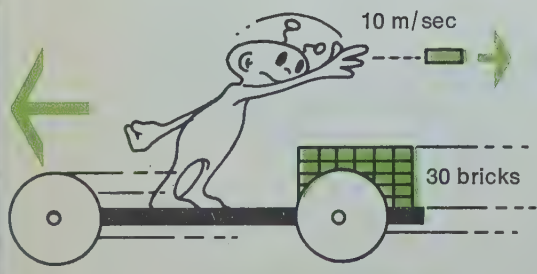


Now suppose you throw the bricks out one at a time instead of all at once (Figure 4).

If you threw only 1 brick at 10 m/sec, then the force on the cart would be only $\frac{1}{60}$ as much as before. This smaller force must act not only on you and the cart. It must also act on the remaining 59 bricks.

The force from throwing 1 brick is $\frac{1}{60}$ of the force when 60 bricks are thrown. This smaller force is used to speed up almost twice as much mass (you, the cart, and 59 bricks). The change in the cart's speed will be much less than when 60 bricks are thrown away all at once.

Figure 5



With each succeeding brick that you throw, the cart speeds up by a slightly greater amount. When the 30th brick is thrown, the force is still $\frac{1}{60}$ of the force with 60 bricks. But now the cart's total mass is down to $1\frac{1}{2}$ times as much as that of just you and the cart. There are 30 bricks remaining. So the cart will speed up even faster (Figure 5).

Every time another brick is thrown away, the force in the opposite direction produces an increase in speed.

It is possible to calculate how the speed of the cart changes. These calculations show that throwing all the bricks away at once produces more change in speed than throwing them away one at a time.

However, it isn't easy to throw out all the bricks at once. There are two other ways that you could make the cart go faster. You could (1) throw each brick away with a greater speed, or (2) carry a bigger load of bricks to throw away.

There is a limit to the speed that can be given the thrown bricks. So it seems that you will simply have to carry more bricks if you want to go faster.

You and your cart are like a rocket and its payload. Your mass represents the payload. The cart represents the rocket. The mass of the bricks (fuel) just equals the mass of the cart and you. If you carried 80 times as much mass in bricks as your mass—around 4000 bricks—the situation would be closer to the fuel-spacecraft mass relationship of the Saturn-Apollo mentioned on the first page of this excursion.

The best way for you to do it would be to have several carts hooked together. As soon as all the bricks were thrown from one cart, you could cut it loose. Then you wouldn't have to use energy to speed up that cart (Figure 6).

For the mathematically inclined, it would be possible to calculate all the changes in speed that result from throwing one brick at a time. Then all these changes in speed could be added up to get the total change. If this were done, the total change in speed would be about 7 m/sec. It would be 3 m/sec less than the result of throwing all the bricks at the same time. This "lost" 3 m/sec is the price that you pay for speeding up the remaining bricks along with you and the cart

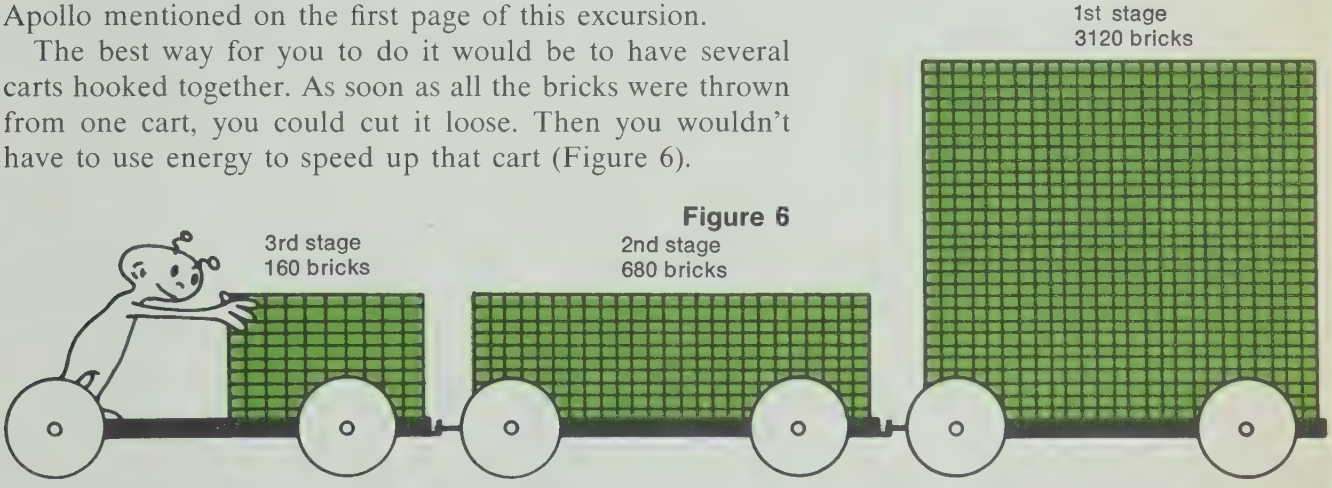


Figure 6

When the 3120 bricks are thrown from the first stage and the cart is dropped off, about 78% of the beginning mass is gone. Then 17% is thrown away in the second stage, and 4% in the third stage. All that is left is a little over 1% of the amount that started out.

Now perhaps you see the reason for the different rocket stages. And you also can see why such a big first stage is needed on the Saturn-Apollo. After the third stage has put the spacecraft into orbit and sent it on its way to the moon, it is dropped off, too. All that remains of the 2 900 000 kg that lifted off the pad is the spacecraft and the occupants, with a mass of about 45 000 kg.

As seen in Chapter 3, the Saturn-Apollo has a relatively low change in speed—about 1.9 m/second every second—close to the earth. But by the time it has used all its first-stage fuel, the mass is so much less (and the drag is less on the spacecraft, and the rocket motors are more efficient because of decreased air density) that the change in speed is about twenty times as great as it was near the ground.

All Systems Are Go

CHAPTER EMPHASIS

Students investigate the factors that influence a body near the surface of the earth and determine the speed necessary to orbit a body. They then see how these factors change at higher altitudes, and apply their findings to satellite orbits and to taking a trip to the moon.

4

EQUIPMENT LIST

Per student-team
1 force measurer, thick blade
1 ball holder, bolt and wing nut
2 steel balls
1 glass marble
1 meterstick
1 force-measurer pin
25 cm of twine

Excursions 4-1, 4-2, 4-3, and 4-4 are keyed to this chapter.

MAJOR POINTS

1. Dense objects projected horizontally from a point above an earth plane fall to the plane's surface in the same time that the same objects would if dropped from that point.
2. It is shown that (a) a greater unbalanced horizontal force on a dense object makes it go a greater distance before hitting the earth and (b) the time for a body to fall some distance toward the earth does not depend on its horizontal speed or its mass; it depends only on the force of gravity.
3. By extrapolation of the experimental results and deduction, a model is constructed which shows that an object traveling parallel to and near the earth's surface at some minimum uniform speed (8 km/second) will orbit the earth at that same height.
4. The relationship of the distance from the center of the earth and the force of the earth's gravity, when plotted and extrapolated, shows that the force of gravity continually decreases with increased distance but never becomes zero.
5. If the forces involved in the circular motion of an object are balanced with the force of gravity at the height of that object, the object will stay in a circular orbit.
6. A small imbalance of these forces (produced by a speed increase of up to 3 km/sec) produces an elliptical orbit.
7. A large difference in these forces (produced by a speed increase of more than 3 km/sec) causes the object to leave the earth and head for outer space.
8. A free-return path between the earth and the moon is a figure-8 path that requires no additional rocket power to continue indefinitely.

You have learned how to get a rocket higher and how to make it go faster. But what must be done to put the space vehicle into orbit or to send it on its way to the moon? The ideas of an old scientist friend may help you with these questions.

About 300 years ago, Isaac Newton described the paths a body would follow if given a sidewise (horizontal) push. He pictured the body as being projected from the top of a mountain at V (Figure 4-1). Orbits from V ending at D, E, F, and G respectively are for bodies that were thrown with increasingly greater horizontal speeds. But suppose the body were given enough horizontal speed. Newton theorized that it would continue to move all the way around the earth, as in A. In other words, the body would go into orbit.

How much horizontal speed would be necessary to put the body into orbit around the earth? An activity can help you begin finding out. Work with two partners. You will need the following equipment:

1 force measurer, with thick blade and 0–10 newtons scale
1 ball holder, with 2 bolts and 2 wing nuts
1 steel ball
1 metrestick
1 special force-measurer pin
25 cm of twine

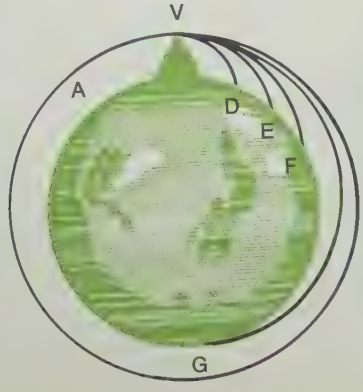
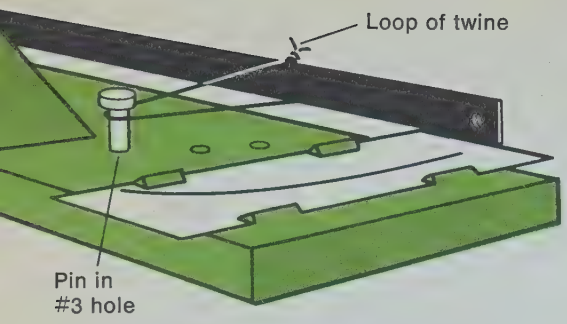


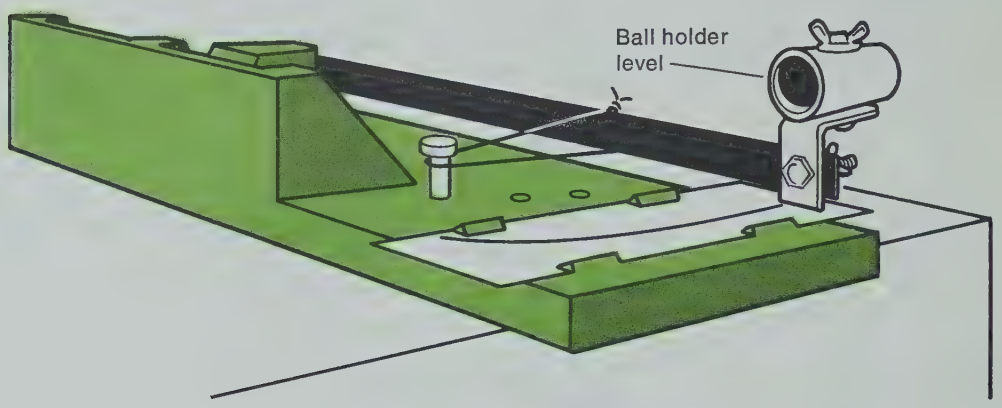
Figure 4-1

9. The time of an object's orbit about some planet, star, or the like, is called the period of the satellite. This value decreases with increased distance between the object and the orbited body.
10. To achieve a lunar orbit, the force of lunar gravity at the height of the orbit must be balanced with the force of the circular speed of the object. Therefore, a rocket must slow down after its trip from the earth.
11. Air resistance and the force of gravity slow down rockets leaving the earth.
12. This air resistance heats the object and its surrounding atmosphere.

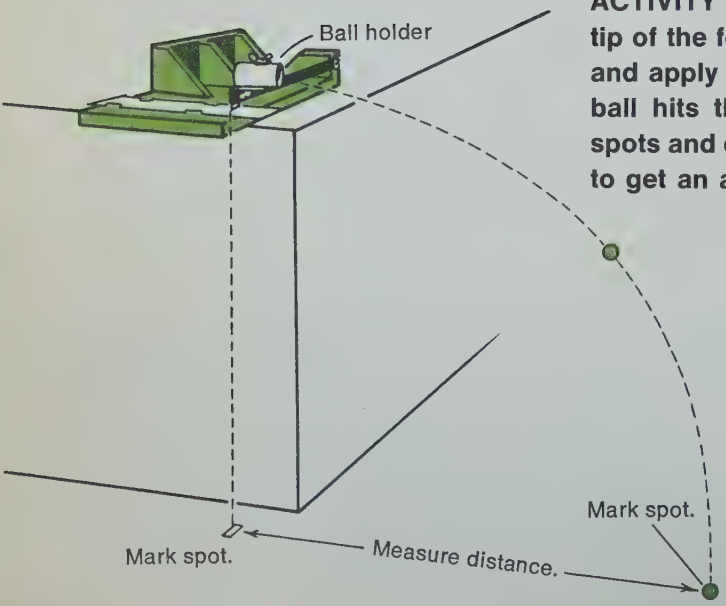


ACTIVITY 4-1. Have the thick blade on the force measurer. Push the special pin into hole #3 on the force measurer. Then tie a loop of twine around the blade and the pin so it's just snug. This will keep the blade from going beyond the edge of the force measurer.

ACTIVITY 4-2. Fasten the ball holder to the end of the force-measurer blade. Zero the scale. Hold the force measurer on the corner of a flat desk or table in a spot where the steel ball can be projected without hitting other objects. One partner should hold the force measurer securely to the table. The second partner should operate the force-measurer blade. The third person should mark the spot where the ball hits.



ACTIVITY 4-3. Mark the spot on the floor directly under the tip of the force-measurer blade. Put a steel ball in the holder and apply a 2-N force to the blade. Mark the spot where the ball hits the floor. Measure the distance between the two spots and enter the measurement in Table 4-1. (You may wish to get an average measure for the 2-N trial.)



Careful monitoring may be necessary for these activities. Some students may want to see how far (and at whom) they can shoot the steel ball. Some slight adjustments may be necessary for the ball holder. It is important that the launcher tube be exactly level, which may necessitate adjusting the bend in the angle bracket a small amount. Locating the spot on the floor directly under the tip of the force-measurer blade may be done by (a) using a sinker on the end of a piece of string for a plumb bob, or (b) dropping a steel ball from the tip of the blade and noting exactly where it hits. Perhaps the students can come up with other alternative methods.

Trial	Force (newtons)	Distance (metres)
1	2	
2	4	
3	6	
4	8	
5	10	

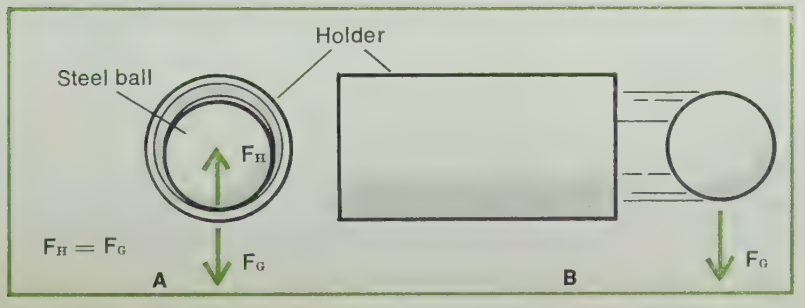
Table 4-1

The distances in Table 4-1 should be directly proportional to the force applied. However, they probably will vary somewhat because of several factors.

Perhaps of interest to you, but not necessary for the student, is the fact that all the different paths, or trajectories, of the ball are sections of parabolas.

ACTIVITY 4-4. Apply forces of 4 N, 6 N, 8 N, and 10 N to the steel ball. Measure the distances and enter the measurements in Table 4-1. Remember to keep the force-measurer's blade tip over the spot you marked on the floor.

While the ball is supported in the holder, the holder pushes upward on the ball as strongly as gravity pulls downward. Figure 4-2A shows this. As soon as the ball leaves the holder, as in 4-2B, the force of gravity is unopposed, and the ball falls.



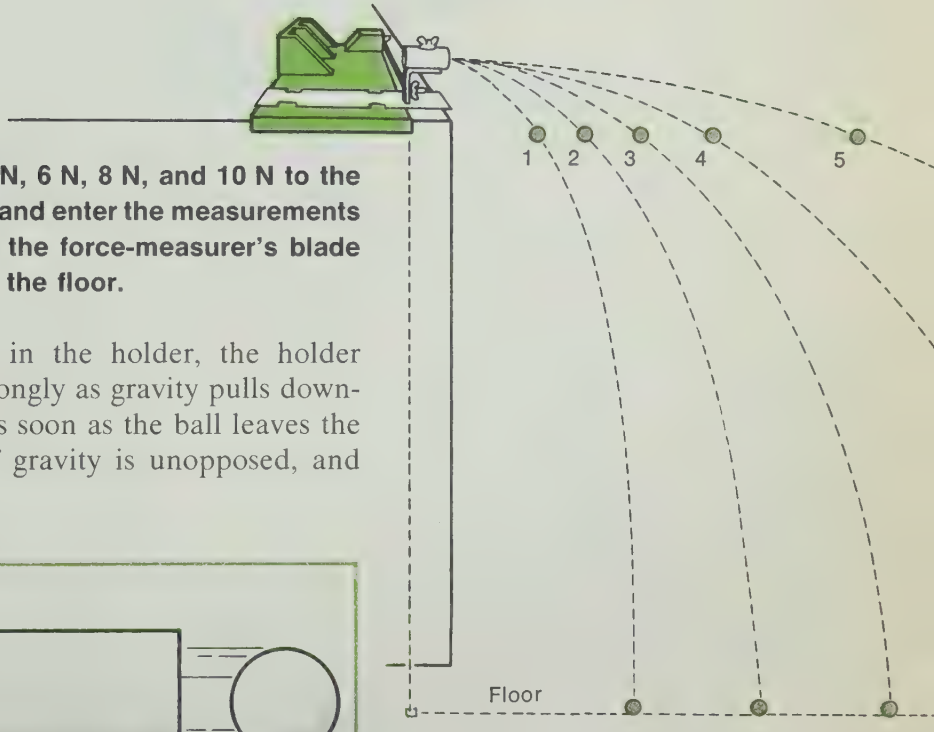


Figure 4-2

☐**4-1.** Did the horizontal distance the ball traveled before hitting the floor seem to depend on the amount of force applied?

4-2. It would go farther and farther before it hit the level surface.

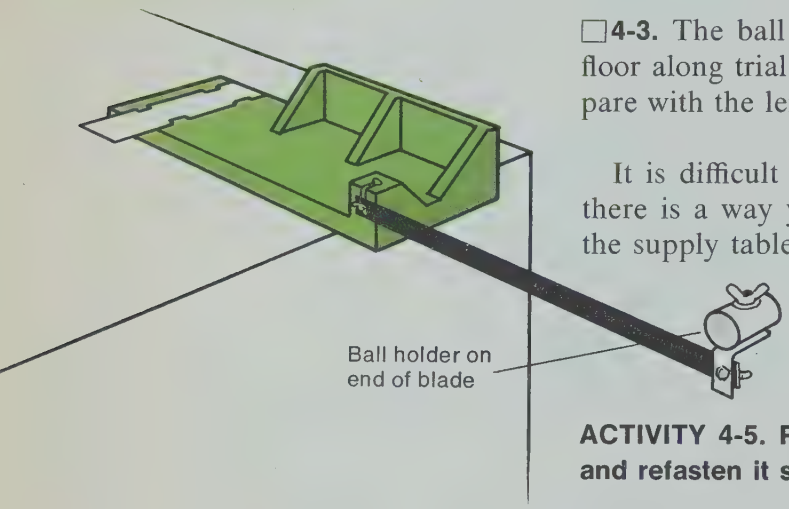
☐**4-2.** What do you think would happen to the ball if you applied more and more horizontal force?

The horizontal distance the ball travels through the air depends on how much force you apply. You may also suspect that the horizontal distance traveled depends on how long the ball is falling.

4-3. The same (Students may not have a correct answer at this point, but their answers should prove interesting.)

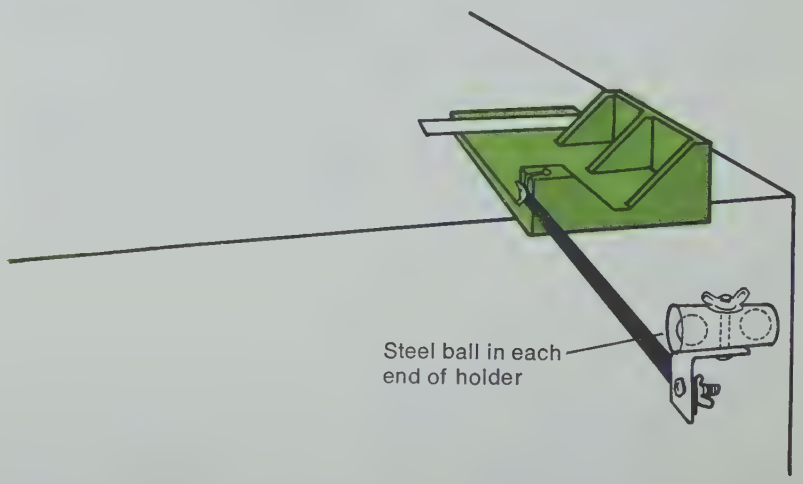
☐**4-3.** The ball takes a certain length of time to reach the floor along trial path 1. How does that length of time compare with the length of time along trial paths 2, 3, 4, and 5?

It is difficult to be sure about your answer, isn't it? But there is a way you can check. Get another steel ball from the supply table.



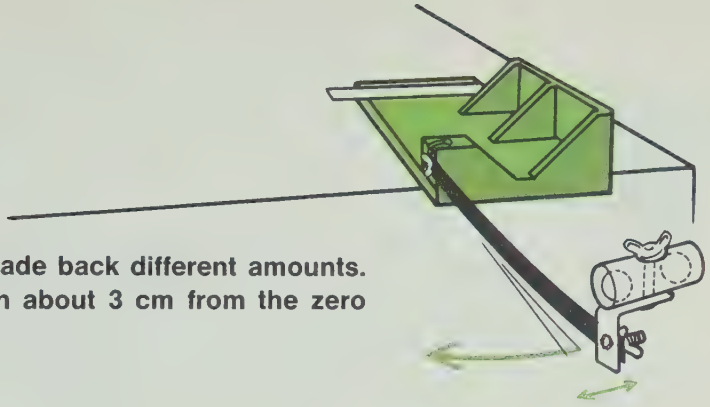
ACTIVITY 4-5. Remove the blade from the force measurer, and refasten it so that it points in the opposite direction.

Once again, it is important that the ball holder be level in this new configuration. If it tips up either way, not only will it be impossible to keep one ball in the holder, but also the other one will be projected slightly upward, not horizontally, and the time to fall to the floor will be affected. At best, the times for the two balls to hit the floor will only be approximately the same. The projected ball remains in the holder for a longer time than the ball that drops straight down. This gives the latter a "head start." The greater amount the blade is pulled back (Activity 4-7), the more pronounced the difference will be.



ACTIVITY 4-6. Put a ball in each end of the holder. Have one partner hold the force measurer firmly on the table. Pull the blade back a small amount and release. *Listen carefully for the sound of the balls hitting the floor.*

☐**4-4.** Did the balls strike the floor at about the same time?



ACTIVITY 4-7. Try pulling the blade back different amounts. But don't pull it back more than about 3 cm from the zero position.

You probably noticed that one ball fell almost straight down to the floor. The other went out and then down, following a longer path before it hit.

☐**4-5.** Did the distance that the one ball was projected make any difference in the time it took to reach the floor?

☐**4-6.** What does this activity suggest about the time it takes for the ball to reach the floor along the various paths in Activity 4-4?

☐**4-7.** So far as you can tell, does the time to reach the floor depend on how fast the ball is moving horizontally?

☐**4-8.** Does the time of flight seem to depend on the horizontal distance that the ball moves?

☐**4-9.** What two motions does the ball have after the force is applied?

Neglecting air resistance, which is insignificant in this case, there are only two factors that affect the time for the ball to reach the floor—the pull of gravity and the height of release above the floor. Thus, in question 4-9, the two motions are the horizontal one resulting from the projecting force and the vertical one resulting from the force of gravity. These two motions are at a right angle to each other.

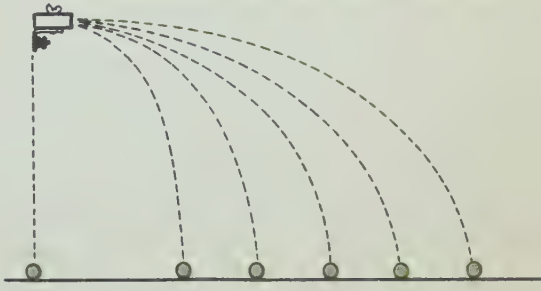
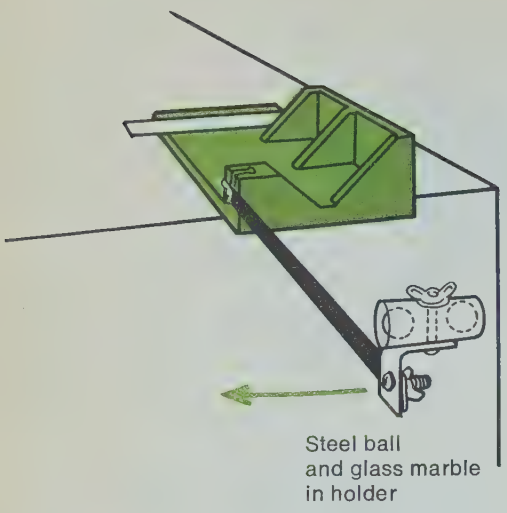


Figure 4-3

From this activity, it appears that *the force of gravity always acts to move the ball downward. This downward motion is independent of (not affected by) the horizontal motion of the ball.* In other words, *the force applied to project the ball horizontally has no effect on the force of gravity.* That's why it takes the ball the same length of time to fall to the floor. It doesn't matter if it falls straight down or along a curved path. As long as the ball falls from the same height, the time of fall will be the same (see Figure 4-3).



One other thing about falling bodies. Does the time of fall depend on the mass of the object? Get a glass marble the same size as the steel ball, and do the following activity.

ACTIVITY 4-8. Put the glass marble and the steel ball in the holder and launch them as before. Listen for the sound as they hit the floor. Try changing them around so that each one is projected and each one is dropped.

The steel ball has more than twice the mass of the glass marble.

☐**4-10.** Did the mass of the ball make a difference in the time of fall?

4-10. No

Students may have difficulty accepting ▫ No answer to question 4-10, and this can be a good lead-in to Excursion 4-1, which discusses the idea.

The scientist Galileo made measurements on falling bodies. He found that near the earth an object will fall almost 5 metres in one second. If you would like to know more about Galileo's work, do **Excursion 4-1,** "Time to Fall."

EXCURSION

Problem Break 4-1 is extremely important in that it is aimed at determining by reasoning the basic orbiting speed at the surface of the earth. From this basic speed all other speeds in orbits of various heights can be determined. It calls for a thought experiment because the necessary information is difficult to obtain empirically. You may have to spend some time in small-group or individual discussion to clear up the concepts.

PROBLEM BREAK 4-1

Your job is to figure out how fast you would have to propel an object to put it into orbit. This is called the *orbiting speed.* Use your knowledge of the way bodies move and the forces that act on them. You should enter the orbiting speeds for the different altitudes of the satellite in Table 4-2 in your Record Book.

To begin the problem, you need to find the orbiting speed at the surface of the earth. Of course, you realize that air friction would slow an object at this low altitude. However, you are only interested in what the speed would have to be. To help you get started, do the following thought experiment.

Suppose you moved your ball launcher to the shore of the ocean on a day when there were no waves to stop the ball. As you increased the propelling force, the steel ball would go farther and farther before falling into the ocean. You

know that the surface of the ocean is not really flat. It curves downward with the curve of the earth. Suppose you could propel the ball fast enough so that its curving path was exactly the same as the curve of the earth's surface (Figure 4-4).

Figure 4-4

□**4-11.** What would happen to the ball?

4-11. It should orbit the earth (disregarding air friction or running into anything).

Near the earth an object will fall about 4.9 m in one second. Suppose you set your imaginary launching platform at a height of 4.9 m above the surface. If the earth were flat, your ball would hit the earth in one second no matter how far you threw it. But the earth is curved—it curves downward about 4.9 m for every 8 km of distance around the surface. Thus, an object traveling at a speed of 8 km per second would always remain at the same height above the surface as the height of your launching platform (see Figure 4-5).

The students are asked to accept on faith the statement that the earth curves downward 4.9 m for every 8 km of distance around its surface. If you or a capable student who understands enough about right triangles to use the Pythagorean Theorem (the square of the hypotenuse of a right triangle equals the sum of the squares of the other two sides) want to prove the relationship, it is not difficult. One side of the right triangle is the radius of the earth, 6 371 000 metres. The hypotenuse is this same radius plus 4.9 metres, or 6 371 004.9 metres. If you square the larger number and subtract the square of the smaller number from it, the square root of the difference will be remarkably close to 8 km (7902 m).

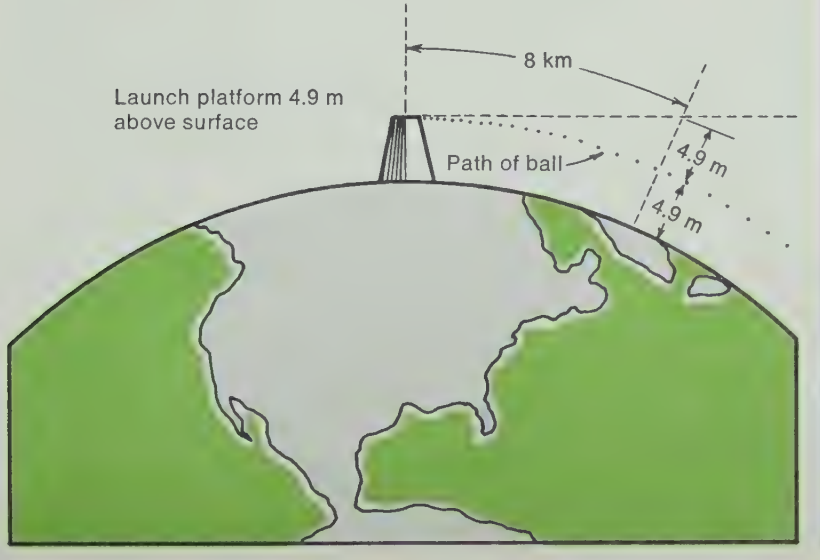


Figure 4-5

The figure that is entered on the first line of Table 4-2 is 8000 m/sec. Notice that it calls for metres, not kilometres, per second. All the other entries in the table will be computed from this figure.

The thought experiment should have given you the orbiting speed for a body just above the surface of the earth. The correct figure is entered on the first line of Table 4-2.

☐**4-12.** Would the orbiting speed be the same, faster, or slower at a height 10 000 km above the earth?

If you had trouble with this question, you will discover the answer as you complete Table 4-2.

Table 4-2

Height of satellite above surface (km)	Fraction of speed at surface of earth	Orbiting speed of satellite (m/sec)
0 (at surface)*	1.00	8000
160	0.99	
1000	0.92	
2000	0.86	
3000	0.82	
4000	0.78	
5000	0.74	
6000	0.71	
7000	0.68	
8000	0.66	
9000	0.64	
10000	0.63	
380 000 (moon)	0.13	

*Consider this the same as 4.9 m above the surface.

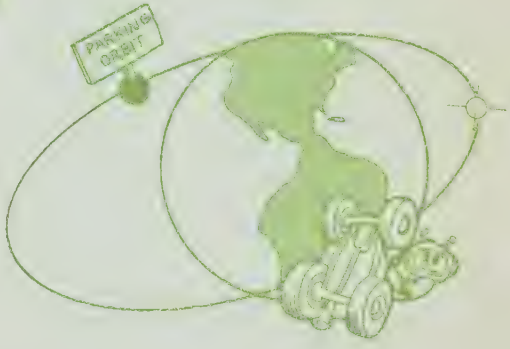
As you move farther out from the earth, the force of gravity decreases. Thus, a body will not fall as far in one second. At the lowest satellite orbit height, 160 km, gravity will be 0.99 of the surface value. At that height an object will fall 0.99 of 4.9 metres in one second. This is slightly less than 4.9 metres in one second. With this smaller amount of fall toward the earth, the orbiting speed will have to be 0.99 of the surface orbiting speed to stay the same distance from the surface of the earth. Find this amount and enter it on the second line of Table 4-2 in your Record Book.

Figure the fraction of the surface orbiting speed for each height. Complete the table by filling in these speeds.

The moon is a natural satellite of the earth. At a distance from the earth of 60 earth radii (380 000 km), the gravity pull of the earth is much less than at the surface. The orbiting speed of the moon is only about 0.13 of the speed of a satellite close to the earth's surface. The last line that you filled in in Table 4-2 is the orbiting speed of the moon.

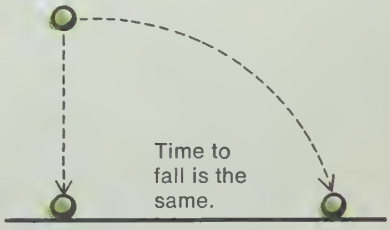
The decimal fractions of speed at the surface of the earth are rounded off to two decimal places. Therefore, the orbiting speeds in the last column need not be carried to more than two significant figures. Thus, 8000 × 0.99 is 7900, 8000 × 0.92 is 7400, 8000 × 0.86 is 6900, etc. In the last line, 8000 × 0.13 is 1000 m/sec, the orbiting speed of the moon.

Even 300 years ago, Newton realized that an object could not be orbited at the surface of the earth. The air drag would slow it too much. But at an altitude of 160 km, the friction of the air is very small. This distance is the *parking orbit* that is used for satellites.



Now let's sum up your knowledge about the motion of an object above the earth's surface.

1. The time that it takes an object to fall to the earth is not dependent on the body's horizontal speed or its mass. The time of fall does depend on the force of gravity (Figure 4-6). Near the surface of the earth, the force of gravity causes a body to fall 4.9 m in one second.



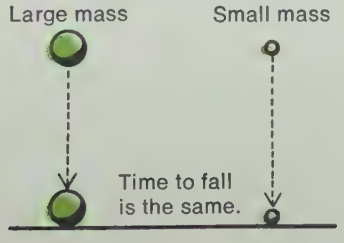


Figure 4-6

The three summation statements here and on the next page might be useful for small-group discussion or for testing. It is interesting to note that statements 1 and 3 are the subjects for Excursions 4-1 and 4-2. Therefore those that are having trouble might be referred to one of them.

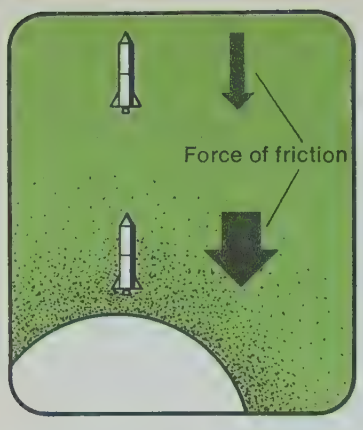


Figure 4-7

The decrease in the force of gravity is inversely proportional to the square of the distance from the center of the earth. Thus, at about twice the distance, the force is $(\frac{1}{2})^2$, or $\frac{1}{4}$ as much. Excursion 4-2, keyed here, discusses this further. This may raise the question of weightlessness with some students. They may have read about astronauts and their equipment in their spaceship floating in a weightless condition. Yet they find out in this chapter that although the force of gravity (weight) gets less and less, it never actually goes to zero.

Anybody or anything can be weightless anywhere by being in free fall. An astronaut in orbit is falling toward the earth at all times, but his orbital path is such that the earth curves away at the same rate that he falls. Thus, he gets no closer to the earth. In the same way, the moon is weightless with respect to the earth's gravity. It is falling toward the earth as it travels around its curved path.

You can demonstrate weightlessness in the classroom. You know that a force measurer normally measures weight. Hang an object on the blade with heavy string, and the reading on the scale indicates the pull of gravity on the object—its weight. Hold the force measurer high above the floor. Have someone ready to catch it before it hits the floor. Then release it with the object attached. If you look fast, you can see that on the way down the scale reading is zero. The object is weightless while in free fall.

EXCURSION

2. The atmosphere near the surface of the earth exerts a force on a moving object. The air particles rub against the object and slow it. The friction of the particles against the object produces heat. As the moving object gains altitude, the atmosphere becomes thinner; fewer particles are there. Thus the frictional force is less, and there is less drag on the object (Figure 4-7). For the Saturn-Apollo rockets, air drag is enough to cut down the speed of the rocket at first-stage engine shut-down by about 460 m/sec from what it would be if there were no air drag at all. However, the rocket continues to climb rapidly upward because of its mighty thrust.
3. The force of gravity, which you investigated in Chapter 3, makes it hard for the rocket to get away from the earth. This force is an extremely important one throughout space. The effect is felt not only from the earth but from the moon and other heavenly bodies as well. Near the surface of the earth, gravity exerts a large force on a body. As the body goes away from the earth's surface, the force of gravity decreases (Figure 4-8). For example, at a point 6500 km above the earth's surface (about twice the distance from the center of the earth to the surface), gravity force is only $\frac{1}{4}$ what it is at the earth's surface.

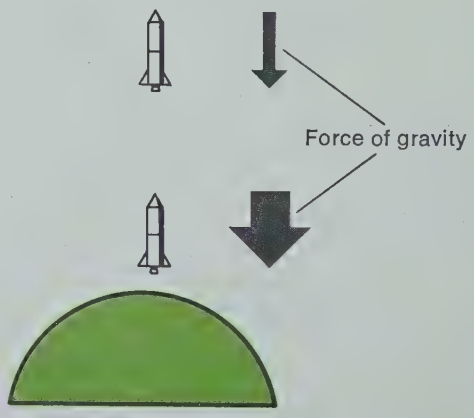


Figure 4-8

If you would like to find out more about gravity and its effect on objects, try **Excursion 4-2,** "The Falling Apple."

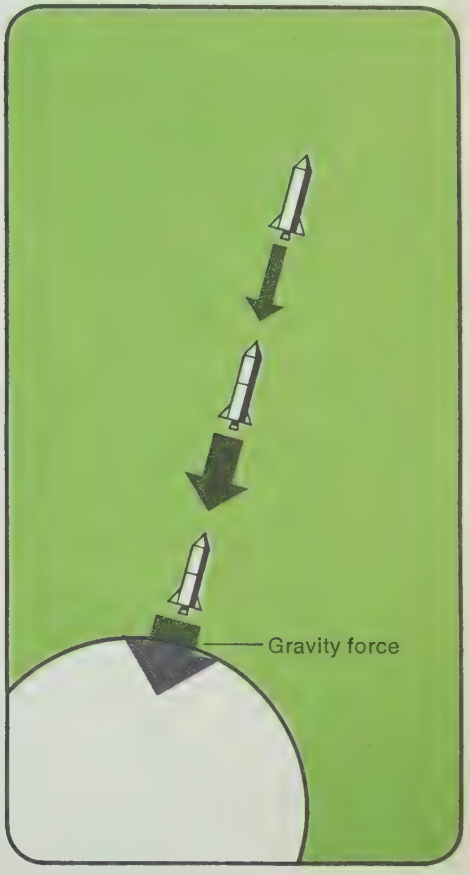
The force of gravity on an object is called the object's weight. The data in Table 4-3 illustrates how the weight of an object changes as it gets farther from the earth's surface.

☐**4-13.** Use the data in the table and the grid in Figure 4-9 in your Record Book. Draw a graph of the change in weight with increased distance from the earth's surface.

Urge students to draw a smooth, best-fit graph in the Record Book. It should curve downward to the right. Note that the distance intervals in Table 4-3 are not uniform.

Table 4-3

Distance from earth's surface (km)	Weight of object exerting 100 N at surface
0	100
100	97
200	94
500	86
1000	75
1500	66
2500	52
3500	42
4500	34
5500	29
6500	25
7500	21
8500	18



Use your graph to answer the next two questions.

☐**4-14.** At what distance from the earth's surface is the weight of an object 0.5 of its weight at the surface (the place where it would weigh 50 N)?

☐**4-15.** At what distance is the weight 0.25 of its weight at the surface (the place where it would weigh 25 N)?

The weights at various altitudes in Table 4-3 are only approximately correct. For instance, the distance from the earth's surface where the weight is 25 newtons ($\frac{1}{4}$ of what it was on the surface) is really 6371 km, which is the length of the earth's radius.

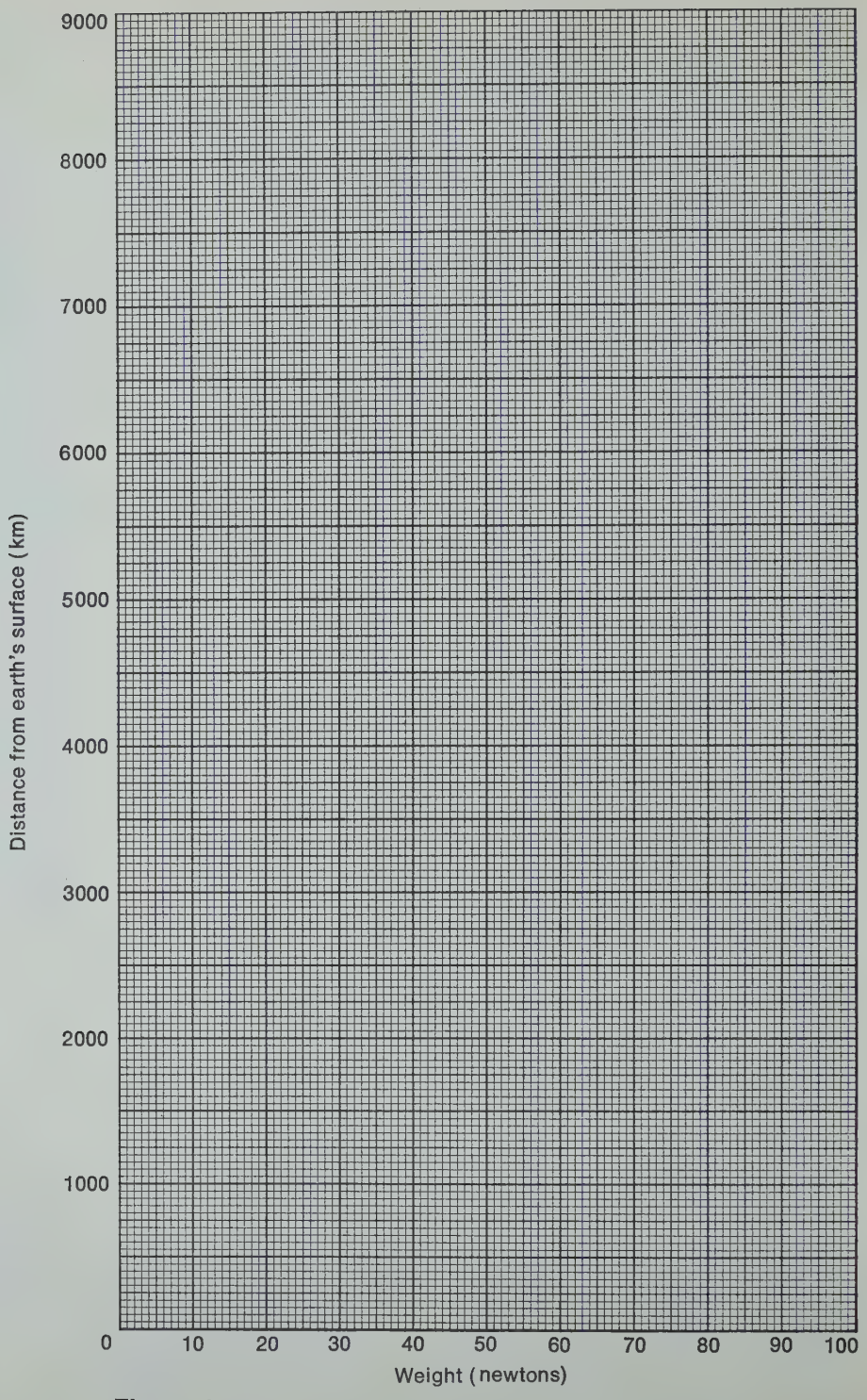

9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10
20
30
40
50
60
70
80
90
100
Distance from earth's surface (km)
Weight (newtons)

Figure 4-9

Notice that question 4-15 could be answered in two ways. It does not state "from what" the distance is to be measured. The force of gravity acts as if all the mass were concentrated at the center of each body. If you're not familiar with this idea, do **Excursion 4-2,** "The Falling Apple." To really compare the forces of gravity, you should add the distance to the center of the earth (the earth's radius) to your distance from the surface. The distance to the center of the earth is 6371 km (Figure 4-10). Add this to the distance in question 4-15.

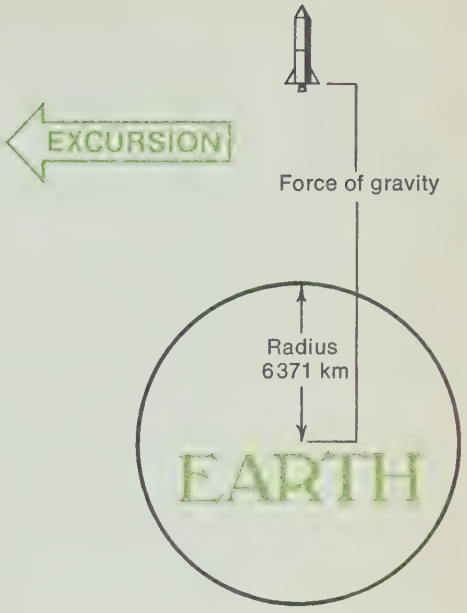


Figure 4-10

4-16. Actually, the answer should be about 14 000 km (6371 + 7624), but the way students are led into it with the 6500-km figure in Table 4-3, the answer they will get will probably be close to 14 200 km.

☐**4-16.** At what distance from the center of the earth is the weight 20 N (0.2 of what it is at the surface)?

The force of the earth's gravity gets smaller and smaller as a rocket speeds away from its surface. However, this force, even though small, continues to exist.

If there is no place where the earth's gravity is zero, it seems reasonable to conclude that a rocket shot straight up will eventually fall straight back to the earth. How, then, can it be put in orbit around the earth? As you have found, it is necessary to give it a horizontal shove to get it into orbit.

TO THE MOON

It's no fun just to get in a car and drive around the neighborhood. You like to go somewhere, to take trips, to see things. The same is true in space travel. The first space flights were concerned with the problem of getting away from the earth and getting into orbit. Once this was mastered, there was the desire to go places.

Let's start with a rocket on the pad and follow it all the way on a journey into deep space. This will help sum up all the ideas that have been developed in this unit.

☐**4-17.** For the rocket to lift off the pad, how must the thrust force compare with the weight force of the loaded rocket?

4-18. Thrust at ground level is much less than the thrust at higher altitudes. (In Chapter 2, students should have discovered that the thrust of the jet was less when it exhausted under water. Since that time very little use has been made of this discovery. For your information, thrust of the Saturn V engines at lift-off is 33 900 000 newtons; at the high altitude of turnout, the thrust has increased to 40 400 000 newtons.)

4-19. Air friction or drag (It increases rapidly due to a rapid increase in speed to a maximum amount, called max-Q, then decreases due to the rapid decrease in air density at higher altitudes.)

4-21. Almost 18 000 mi/h (There are 0.62 miles in a kilometre and 60 × 60, or 3600, seconds in an hour. Therefore,

$$8\frac{\cancel{km}}{\cancel{sec}} \times 0.62\frac{mi}{\cancel{km}} \times 3600\frac{\cancel{sec}}{h} = 17\,856\ mi/h.)$$

RESOURCE

4-22. $365\frac{1}{4}$ days (1 year)

4-23. 5000 seconds (83 minutes or 1 h 23 min)

4-24. Increase the period. (Questions 4-22 and 4-23 give all the clues that are necessary. The earth revolves around the sun at a height of 1 500 000 000 km and has a period of 8766 hours. A satellite revolves around the earth at a height of 6.4 km from the center and has a period of 1 h 23 min.)

☐**4-18.** How will the amount of thrust produced by the engines at ground level compare with the thrust at higher altitudes?

☐**4-19.** As the rocket rises faster and faster, what force opposing its motion will increase to a maximum and then decrease?

☐**4-20.** What other force opposes the rocket motion and decreases as the rocket gets farther from the earth?

You recently found that an object just above the surface of the earth would have to travel 8 km per second in order to stay the same distance from the earth.

☐**4-21.** How many miles per hour is 8 km per second? Have trouble converting miles to km? **Resource 1,** "Measuring Distance in Metric," could help.

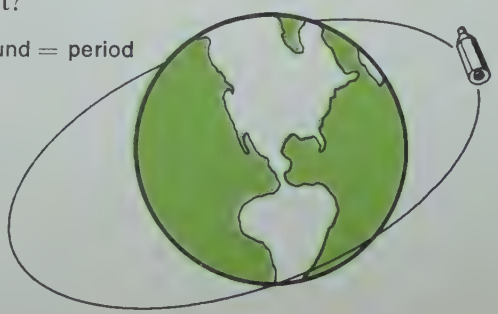
Just above the surface of the earth, the force of gravity is large and the atmosphere is thick. Both of these factors act against the rocket.

The pull of gravity and the thickness of the earth's atmosphere decrease as you go away from the earth's surface. With less gravity, spacecraft far above the earth don't need to travel as fast as those at lower altitudes to stay in orbit.

☐**4-22.** The time needed for a satellite to go once around in its orbit is the *period* of that satellite. What is the earth's period as a satellite of the sun?

☐**4-23.** How many seconds would it take for the object traveling at 8 km per second to make one trip around the earth? (The circumference of the earth is about 40 000 km.)

☐**4-24.** What effect would a higher orbit have on the period of a spacecraft?



Not only does the speed of a body decrease as it orbits farther from the earth, but the body also has farther to travel. So the period gets greater (it takes longer to go around) because of a slower speed and a greater distance. A spaceship orbiting at an altitude of 161 km has a period of just under 90 minutes, and it travels at almost 8000 metres per second. The moon, a natural satellite of the earth, has a period of $27\frac{1}{3}$ days. At its distance—380 000 km—it takes the moon $27\frac{1}{3}$ days to orbit the earth. And because of decreased gravity, the moon's speed is only about 12 percent of the speed of the spaceship that closely orbits the earth.

If you would like to take a further look at satellite orbits, do **Excursion 4-3,** "Orbiting Syncom."

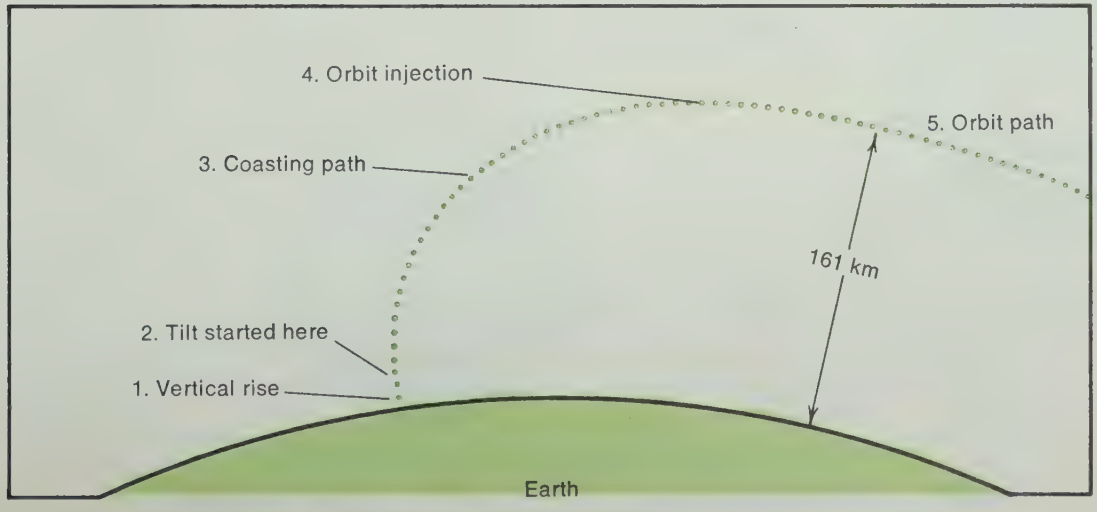
The period of the moon is given here as $27\frac{1}{3}$ days. This means that it takes this long for the moon to go once around the earth and line up again with some distant point in space. However, during that time the earth has moved in its orbit around the sun. Therefore, in order for the moon to come into the same relation with the earth and sun (in other words, from full moon to full moon) it takes $29\frac{1}{2}$ days.

EXCURSION

Excursion 4-3 is for extension purposes. It uses two graphs to solve the problem of satellite height, and may be difficult for some students.

Let's get back to our rocket ship. Putting a satellite into orbit involves five steps. Figure 4-11 illustrates these steps.

Figure 4-11



The idea of a slightly increased speed above the circular orbit speed causing an elliptical orbit may be difficult to understand. Remember that the idea of elliptical orbits was one of the problems that Kepler struggled with the most. A circle, as a perfect curved line, was considered the only fitting path for a celestial body, and the elliptical path was accepted with great reluctance.
Further information on orbits is given in the Introduction in this Teacher's Edition.

1. The rocket rises vertically from the pad.
2. After rising some distance vertically, it is tilted.
3. It climbs on a curving path to orbit height.
4. As the rocket reaches the necessary speed for orbiting, the engines shut down.
5. It then moves along the circular orbit path. (The orbit will be circular only if the rocket has exactly the right speed. If it is less than the correct amount, the satellite will come back closer to the earth. There it will encounter denser atmosphere, which will slow it even more. It will eventually cause it to return to the earth or burn up.)

It is now time for the rocket to head out into space. How can this be done? The key is more speed. A slightly greater speed gives an elliptical orbit. But if the speed is increased enough, the rocket will escape into space. The following figures and explanations will help to make this clear.

At speeds less than about 8 km/sec (28 800 km/h), the object will reenter the earth's atmosphere and return to the surface (Figure 4-12).

Figure 4-12

If the speed is exactly correct for the altitude of the object, a circular orbit will be the result. At an altitude of 161 km, this speed is just under 8 km/sec (Figure 4-13).

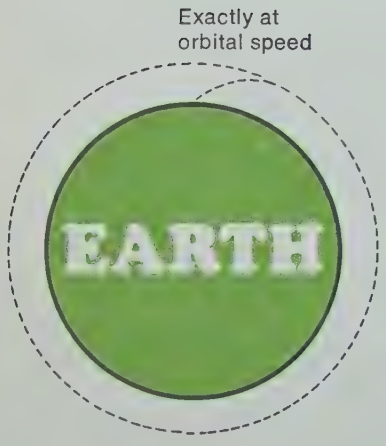


Figure 4-13

At speeds from 8 km/sec to 11 km/sec (28 800 km/h to 40 000 km/h), the orbit will be elliptical. The greatest speed will be closest to the earth (perigee). The slowest speed will be farthest from the earth (apogee). (See Figure 4-14.)

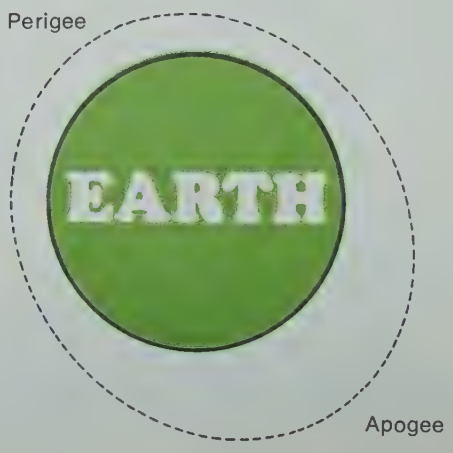


Figure 4-14

If a speed greater than 11 km/sec (40 000 km/h) is reached, the object will escape the gravitational pull of the earth. It will head for outer space (Figure 4-15). This necessary speed is given to the Apollo spacecraft by a "burn" of just under 6 minutes of the third-stage booster. This additional force increases the speed just over 3 km/sec.

Figure 4-15

If the spacecraft leaves its parking orbit around the earth at just the right time, it will head for the moon. It will be on a "free-return path." This means that with only slight corrections, it will swing around the moon and head back to the earth. Figure 4-16 diagrams this path, which looks like a huge figure 8.

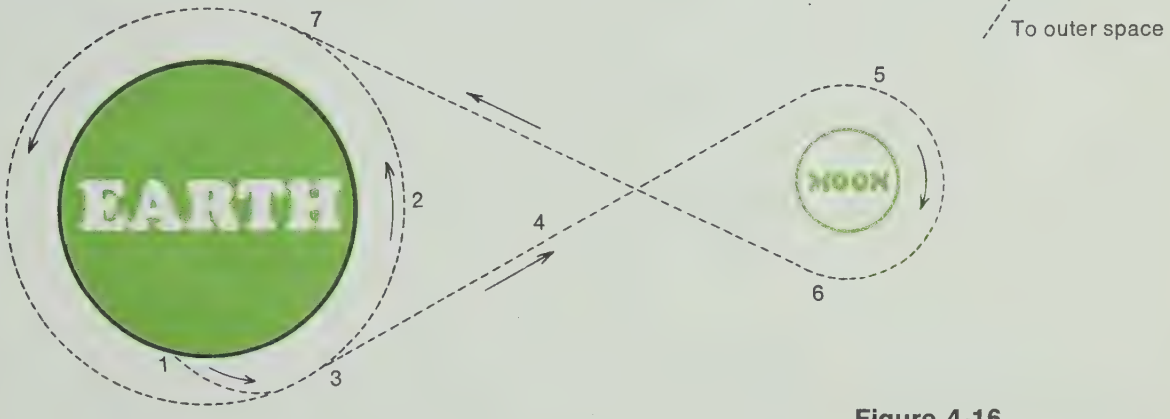


Figure 4-16

No rocket power is needed on this free-return path to and from the moon. The spacecraft would continue this figure-8 path indefinitely, swinging first around the moon and then around the earth.

Here are the steps needed to get the free-return path to and from the earth to the moon (Figure 4-16).

1. Lift-off and insertion in parking orbit
2. Parking orbit around the earth
3. Insertion in free-return path to the moon
4. Free-return path to the moon
5. Capture by the moon's gravity and half-orbit around the moon

The free-return path to and from the moon is another difficult concept. Students may find it hard to accept the statement that no additional rocket power is necessary to keep a satellite in this path indefinitely. However, this is what happened with Apollo 13 when it had the explosion in space. It swung around the moon and headed back to the earth without any additional rocket boost, and returned to the earth safely.

6. Leave the moon's gravity and head back to the earth on free-return path
7. Capture by the earth's gravity and half-orbit around the earth

4-25. Slow it down (fire retrorockets).

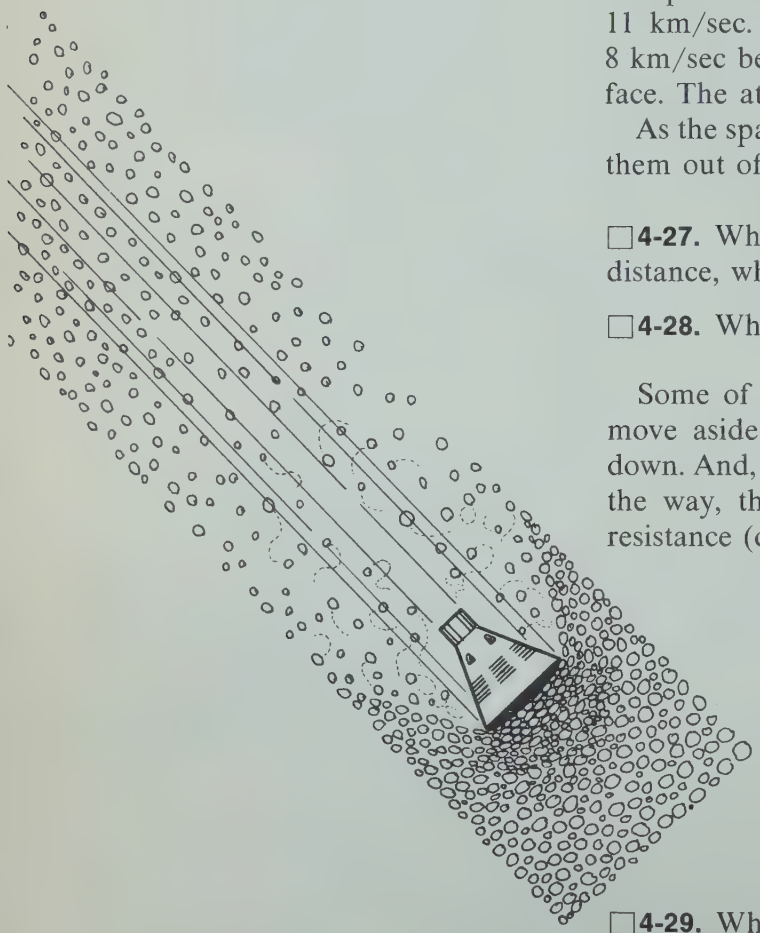
☐**4-25.** If a spacecraft is to stay in a moon orbit for a while, what must be done?

4-26. Speed it up.

☐**4-26.** What must be done for a spacecraft to leave a moon orbit and get back to the earth?

If the craft is to return to the surface of the earth, its direction (point 6, Figure 4-16) must be changed a little. Instead of entering an earth orbit (point 7, Figure 4-16), the craft heads closer to the earth into the upper atmosphere. Its speed at the time it enters the atmosphere is about 11 km/sec. This high speed must be decreased to below 8 km/sec before the craft can come back to the earth's surface. The atmosphere makes this slowing down possible.

As the spacecraft begins to hit particles in the air, it pushes them out of the way. It exerts a force on these particles.



☐**4-27.** When a force is applied to move something some distance, what is done?

☐**4-28.** When work is done, what else is involved?

Some of the motion energy of the spacecraft is used to move aside the particles in air. Thus, the craft is slowed down. And, of course, as the particles in air are pushed out of the way, they rub against the spacecraft. This causes air resistance (drag), slowing the vehicle still more.

☐**4-29.** When air resistance is present, what happens to the surroundings?

At the enormous speed of a spacecraft, a huge amount of heat is produced. So much heat is produced that the craft and its occupants would burn up without some kind of heat shield. You may recall that it takes heat to melt or boil a material. Perhaps the heat that would otherwise do damage can be used to melt and boil a coating on the outside of the spacecraft. With such a material as a heat shield, the heat energy would be used up as it gradually melted and boiled the coating away. The occupants could stay cool. Such a material is now used on the outside of spacecraft. It doesn't harm the vehicle as it burns up. It just gets rid of the heat. If you would like to know more about this process, called *ablation,* do **Excursion 4-4,** "Losing Heat."

You have found out some things about rockets and their operation. You have also found out about travel in space. Who knows? You might be an active member of a space team to the moon or the planet Venus some day.

Before going on, do Self-Evaluation 4 in your Record Book.

Excursion 4-4 is for general interest. It uses a small amount of equipment, and if you feel that you can let the thermometer be used outside of the classroom, it is a good one to be done at home.

GET IT READY NOW FOR CHAPTER 5

You will need ■ supply of old newspapers and a pail or two of clean, dry sand that must be supplied locally. Set up some housekeeping rules for handling the bentonite. This material is reusable indefinitely if it is kept clean, and if it is not spilled around the room. If you have not already done so, the lunar map should be securely fastened to the wall or the bulletin board. You should also procure ■ spool of thread.

You will need to decide how the light bulb and socket (floodlight) will be used in your classroom. The light cord is less than 2 metres long, so students will either have to bring their aluminum pan to a wall receptacle where the light is plugged in, or you will need to supply extension cords for the three floodlight units. The floodlights will be used in Chapters 5, 6, and 7.

Excursion 4-1

Time to Fall

EQUIPMENT LIST

1 steel ball
1 glass marble
String or thread
Tape
Watch or sweep-second clock

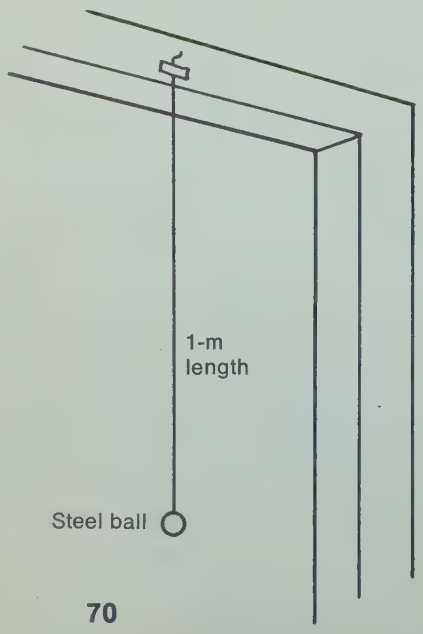
This is a general-interest excursion, with remedial implications on the speed of a falling body.

PURPOSE

To use a pendulum to discover the factors that do or do not affect the rate at which a body falls.

MAJOR POINTS

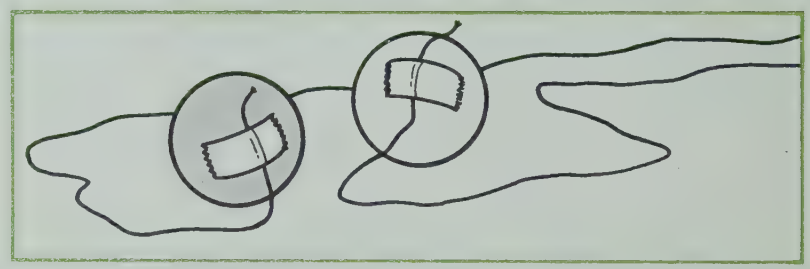
1. Untested, incorrect ideas last a long time.
2. The study of a pendulum leads to the conclusion that its period is
   a. independent of the amplitude,
   b. independent of the mass, and
   c. dependent on length.
3. Neglecting air drag, all bodies falling from a given location fall at the same rate.



Sometimes incorrect ideas last for a long time. The great Greek philosopher and scientist Aristotle stated some rules of motion that lasted for 2000 years. The rules were incorrect, but until Galileo tried some experiments, they were generally believed true. One faulty rule that survived from Aristotle's time (384–322 B.C.) declared that heavy objects fall faster than light ones.

Galileo is said to have discovered something about falling objects when he watched the swinging of a chandelier in the cathedral at Pisa, Italy. As he watched the massive object swing back and forth, he timed it with his pulse. When he returned home, he made pendula of different kinds and timed them in the same way. You can do an activity to discover how a pendulum operates, just as Galileo did. You will need the following equipment:

1 steel ball
1 glass marble
2 pieces of string, each 1 metre long
4 small pieces of tape

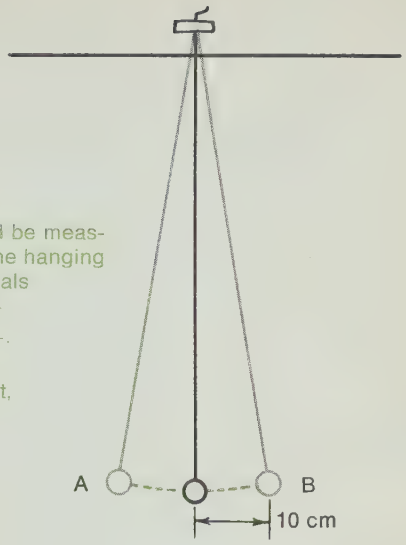


ACTIVITY 1. Use small pieces of tape to fasten one string to the steel ball and the other string to the glass marble.

Now let's see if you can discover the same thing that Galileo did as he watched the swinging chandelier. First use the steel ball.

ACTIVITY 2. Tape the loose end of the string to the top of an opening such as a door or window. Be sure to select an area where the steel ball can swing freely at the end of the 1-metre string.

ACTIVITY 3. Pull the steel ball back about 10 cm and release it. Use a watch or clock to find out the time it takes for 10 complete swings. A complete swing means the ball swings from A across to B and back to A again. You may want to have someone help you with the counting and timing.



There may possibly be students in your classes who are mathematically inclined and would enjoy working with the pendulum formula to figure what the period should be. The formula states that

$$T = 2\pi\sqrt{\frac{l}{g}},$$

where T is the period in seconds, π (pi) is 3.14, l is the length of the pendulum in metres, and g is the acceleration due to gravity, which is 9.8 m/sec² on the earth.

The length of the pendulum should be measured from the top to the center of the hanging ball. Thus, for a 1-m length, T equals

$$2 \times 3.14 \times \sqrt{\frac{1\text{ m}}{9.8\text{ m/sec}^2}}.$$

The quantity under the square root,

$$\left(\frac{1\text{ m}}{9.8\text{ m/sec}^2}\right),$$

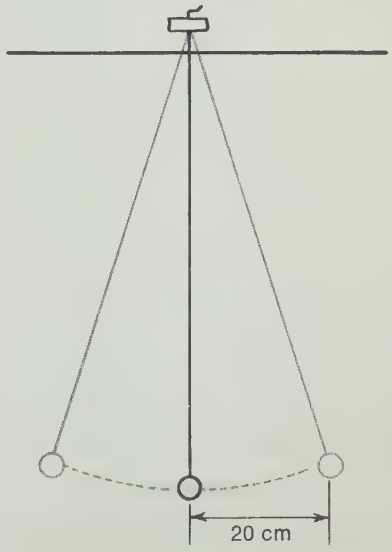
equals 0.102 sec². The square root of this is 0.32 sec. So T equals $2 \times 3.14 \times 0.32$ sec, or about 2 seconds. A 1-m pendulum should take about 2 seconds for a complete swing.

☐**1.** What is the time (in seconds) for 10 complete swings?

☐**2.** What is the time (in seconds) for 1 complete swing?

The time for 1 complete swing of the pendulum (from A to B and back to A) is called the *period.*

ACTIVITY 4. Now pull the steel ball back about 20 cm and release it. Find the time for 10 complete swings again.



In working with the pendulum formula, you can see that the only two factors that affect the period are the length and acceleration due to gravity. For the extremely capable student, you might ask, "What would be the period of a 1-m pendulum on the moon, where g is only $\frac{1}{6}$ as much as on the earth?"

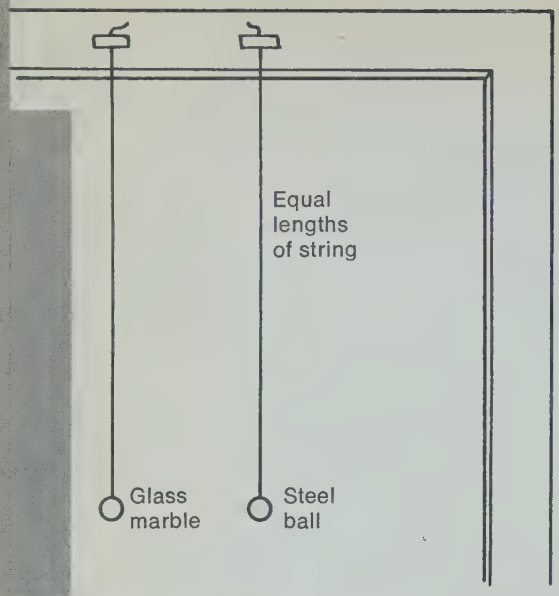
☐**3.** What is the time (in seconds) for 10 complete swings?

☐**4.** What is the period of the pendulum (time for 1 complete swing)?

Compare the periods in questions 2 and 4. If the timing was done correctly, you should have found them to be the same. This is the discovery that surprised Galileo and led him to further investigation.

Next you will experiment with the mass of the ball.

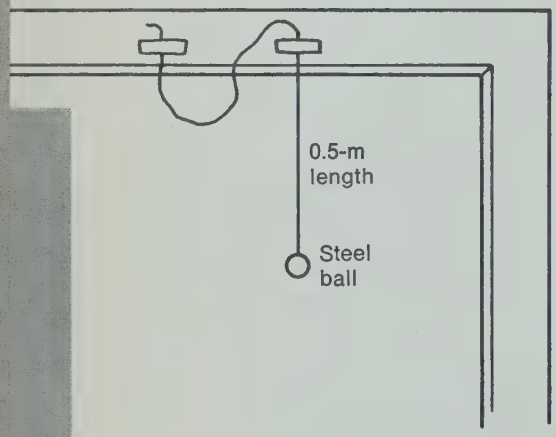
The amount that the ball is pulled back, which controls the amplitude of the swing, can have an effect on the period. Up to a 15° angle of displacement, the period will not be changed by more than 1%. A 15° angle would result from pulling the ball 26 cm to one side. Up to 1% difference in period (0.02 sec) would not be noticeable without special timing instruments. But beyond 15° the effect on period increases rapidly. Just pulling the ball 15 cm more to the side increases the variation to 5%.



ACTIVITY 5. Nearby, on the same support, tape the loose end of the string from the marble. Be sure that the free lengths of the two strings are exactly the same. Pull the marble and the ball back a short distance and release them together.

☐**5.** Compare the periods of the two objects.

The mass of the steel ball is more than twice as great as the mass of the glass marble.



ACTIVITY 6. Shorten the string on the steel ball to 0.5 metre. Pull the ball back a short distance and release it. Find the length of time for 10 complete swings again.

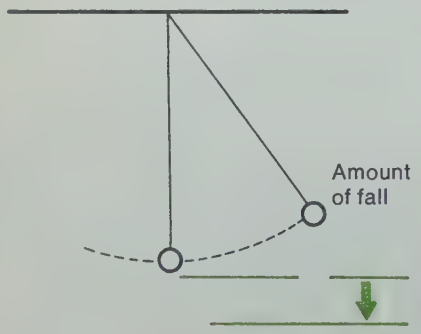
7. The period should be a little less than 1.5 seconds (1.41 sec). In question 8, about all that the student can be expected to say is that it is less than for a 1-m length. Actually, the period varies as the square root of the length; the square root of 0.5 is 0.707, and 2 × 0.707 is 1.414.

☐**6.** What is the length of time for 10 complete swings?

☐**7.** What is the period of the pendulum?

☐**8.** How does this period compare with the period that used a 1-metre length of string?

Figure 1



You have now investigated size of swing, mass of the object, and length of the pendulum.

☐**9.** From your investigations, which of the variables affect the period of the pendulum?

Galileo reasoned that though the object on the end of the string was supported by the string, it was really falling. The string forced the object to travel in an arc (Figure 1). Objects of different mass take equal time to come down when suspended on strings of the same length. So they should take equal time to fall straight down.

Some stories tell of Galileo's dropping objects from the Leaning Tower of Pisa to test this idea. The stories are probably imaginary, but the idea is not. Galileo and others discovered that without air resistance, all bodies fall at the same rate at a given location. In the near-perfect vacuum of outer space, a feather, a steel ball, and the moon all fall equally fast. Or, you could say, equally slow.

Excursion 4-2

The Falling Apple

EQUIPMENT

None

This is a general-interest excursion with historical background.

PURPOSE

To discuss the reasoning Newton used to discover the law of universal gravitation.

MAJOR POINTS

1. Famous scientists, e.g., Newton, often make great discoveries by first analyzing simple systems, e.g., a falling apple.
2. Mathematics (equations and quantitative observations, i.e., measurements) is often used in building a scientific theory or as evidence to support the theory.

What causes the moon to orbit around the earth? Isaac Newton was sure that it would shoot off in a straight line unless there was a force pulling on it. Galileo, who died in 1642, the year Newton was born, had experimented with moving objects. He had found that you need a force to change motion. From his own investigations, Newton knew that this was true. From your past work, you know this, too.

Suppose a round ball is rolled on a smooth, flat surface.

☐**1.** If no other force acts on the ball, what path will it follow?

The statement that a body in motion continues in constant motion in a straight line (and a body at rest remains at rest) unless acted upon by an external force is a statement of Newton's (and Galileo's) first law of motion.

Sometimes the answers to difficult questions are found in strange ways. Newton said that while he was sitting in a garden, he found out why the moon always stayed in its orbital path. As he was thinking of the problem, an apple fell to the ground. Perhaps, thought Newton, the force exerted by the earth on the apple is also exerted by the earth on the moon. The moon might really be falling toward the earth. But if it is, why hasn't it hit the earth?

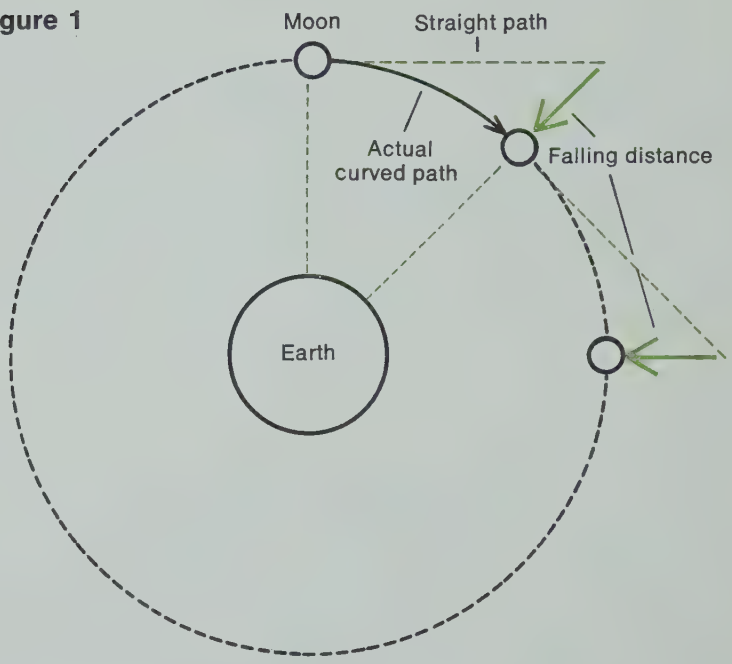
If you could know Newton's entire reasoning, it might have gone like this:

Before the apple fell, it was motionless. When it came loose from the tree, it dropped to earth. Obviously, the earth attracted the apple.

But the moon isn't fastened to a tree. It is moving through space. If no force were acting on it, it would be traveling in a straight line. But a straight path would carry it away from the earth. And I know that the moon follows a curved

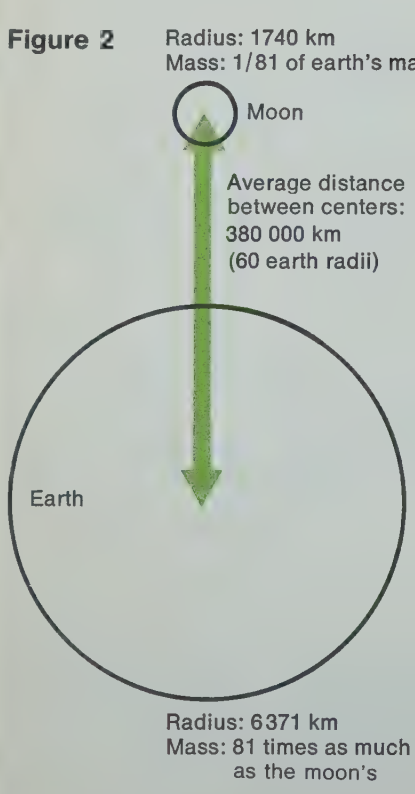
path around the earth. Perhaps the earth attracts the moon, too. If that attraction were very strong, the moon would soon hit the earth. If it were quite weak, the moon would fast be out of sight. But with exactly the right force of attraction, the moon could move two ways at once. It could travel through space while it drops toward earth. At the end of every second, its fall toward earth could just make up for its movement away. So instead of flying away in a straight line, the moon would continue in a curved path around the earth. And that is what it does (Figure 1).

Figure 1



Newton used the laws that Kepler had stated for the motion of heavenly bodies. He combined these laws with his own and with Galileo's laws of motion. Newton discovered that bodies attracted each other with a force that depended on their mass (the amount of substance that each contained). He found that the force of attraction also depended on how far apart the bodies were. And the force changed with the square of the distance between the centers of the objects (Figure 2).

Figure 2



In simplified mathematical terms, the relation could be written thus:

$$\text{Force} = \frac{\text{Mass of 1st} \times \text{mass of 2nd}}{(\text{Distance apart})^2}$$

or

$$F = \frac{m_1 \times m_2}{d^2}$$

Those familiar with physics will recognize that the simplified formula for gravitational attraction given here really needs a constant multiplied into the right-hand side to make it operable in metric units. This so-called gravitational constant, evaluated by Cavendish, is 6.67×10^{-11} N·m²/kg², and gives F in newtons when the masses are in kilograms and the distance in metres. But for the student, the simplified formula is sufficient. It ranks with the laws of magnetic and electrostatic forces and the law of light as one of the important inverse square laws that involve distance of separation.

☐**2.** How many earth radii is the apple from the center of the earth? 2. 1 earth radius

The moon has been measured to be about 60 earth radii from the center of the earth.

☐**3.** How many times farther away is the moon than the apple from the center of the earth? 3. 60 times

Square the number that you got in question 3. (Squaring a number means multiplying it by itself.)

☐**4.** What is the square of the number?

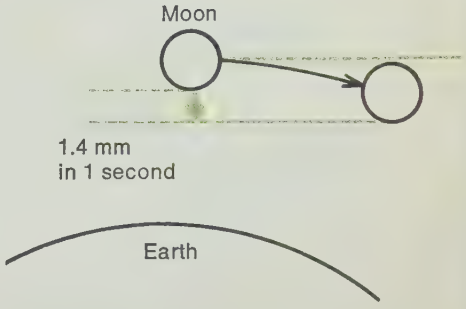
Your answer to question 4 is the number of times greater the earth's pull of gravity is on the apple than on the moon. Bodies fall according to the pull of gravity on them.

☐**5.** How many times faster will the apple fall toward the earth than the moon will fall?

The mass of an apple is much less than the mass of the moon. Therefore, the force on the moon will be much greater than the force on the apple. But the speed of falling does not depend on the mass. It depends solely on the distance apart; so the apple still falls 3600 times faster. An apple, or any other object close to the earth's surface, will fall about 4.9 metres in a second. The moon falls about 1/3600 as much, or just under 0.0014 metre in a second (Figure 3). This is only 1.4 millimetres in a second. With the moon's horizontal motion, this amount of fall is just enough to keep the moon going around the earth in a curved path.

Just think! Newton made these discoveries when he was 24 years old. That's not much older than you.

Figure 3



The earth falls toward the moon, also. But the mass of the moon is so much less than that of the earth that the motion of the earth toward the moon is commonly disregarded. But parts of the earth (for instance, the oceans) are pulled toward the moon enough to have a major effect here on the earth. The tides are an example of this. And of course the earth is falling toward the sun as it revolves in its orbit. All bodies in orbit (planets, satellites, lunar modules, and astronauts) are in free fall toward the body they are orbiting.

Excursion 4-3
Orbiting Syncom

EQUIPMENT

None

This is an extension excursion, but it does have general interest.

PURPOSE

To discuss a special kind of satellite, and to use graphs to find its period and speed.

MAJOR POINTS

1. To be effective, a communications satellite must have a definite height and speed so that it maintains a fixed position above a point on the earth's surface; i.e., the satellite's period must be 24 hours.
2. A graph can be used to show the relation between satellite height and period.

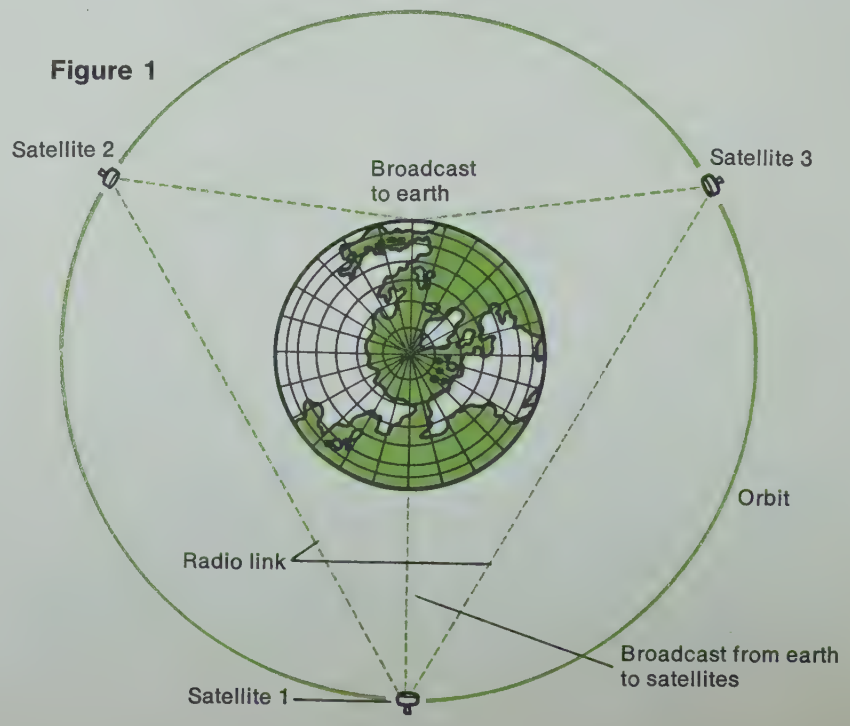
You found that the period (the time for one revolution) increases as the satellite goes farther from the surface of the earth. You also found that the speed a satellite must have in order to stay in orbit decreases at greater heights. However, putting a satellite in orbit farther out in space takes more fuel. Therefore, the lowest possible orbit is used unless there is a special reason for having the satellite in a higher orbit. Some of the satellites that have been launched have needed a distant orbit for just such a special reason.

Early in the space age, the value of satellites for communications was recognized. A radio signal could be beamed to the orbiting object. This signal could be either reflected or rebroadcast to other points of the earth's surface. For this technique to work best, the satellite has to stay over a given point on the earth's surface all the time.

☐ **1.** What must the period of the parking orbit be for a good communications satellite that stays over the same point?

The earth rotates on its axis once every 24 hours. Suppose a satellite could be orbited at the correct height. It could stay over the same spot on the surface of the earth as the earth turned. Then radio messages could be relayed continuously by the satellite. And with a few more such satellites, radio and television programs could be sent to all parts of the globe.

Figure 1



Perhaps you'd like to know how high above the earth a satellite must be to always remain above the same spot. Figure 2 (on page 78) is a graph showing the relationship between satellite height and the period of the satellite. Using the graph, you can find the correct height for a satellite that has a period of 24 hours.

The height of the satellite in thousands of km is shown along the side of the page. The period in hours is shown across the bottom. Use the graph to find the answers to the following questions.

☐**2.** The height of a satellite whose period is 24 hours is how many km?

If you have trouble finding the answer from the graph, take a look at **Resource 5,** "Pictures of Relationships." The last part of the resource can help you read data from the graph.

RESOURCE

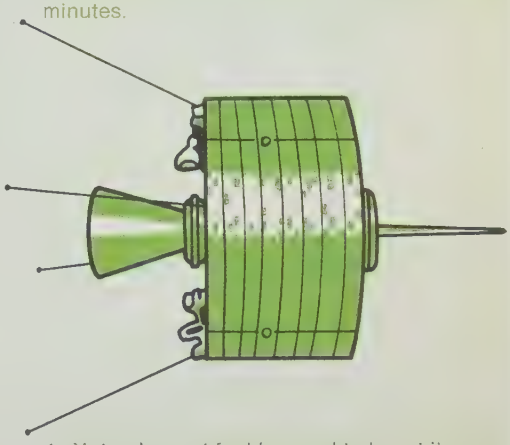
☐**3.** How does the period in question 2 compare with the period of a satellite in a parking orbit at a height of 161 km?

3. The period of a satellite in a 161-cm orbit can be found from Chapter 4, or can be read from the graph in Figure 2. It is about 86 minutes.

On August 19, 1964, the United States placed Syncom 3 in a 24-hour orbit over the Pacific Ocean. It was used to relay the telecast of the Tokyo Olympics, which it did splendidly. Earlier, Syncom 2 had been placed in a 24-hour orbit over the Atlantic Ocean to handle east–west transmissions in that area. Now a complete system of communications satellites has been put in orbit. With them, messages can be sent from any point on the earth's surface to any other point.

The name Syncom is derived from "synchronous communication." *Synchronous* is a word meaning "in time with." Thus Syncom is a communications satellite that is in time with the earth's rotation.

It might surprise you to know that it took more fuel to put the satellite in its high orbit than it would have taken to send it to the moon.



☐**4.** How can this last statement be explained?

4. Not only must fuel be used to boost it away from the earth and up to 36 000 km, but when it gets there, additional fuel must be used to slow it down and insert it into orbit. In sending the same satellite to the moon, it must be given enough speed (escape velocity) to get it away from the earth. Then it coasts the remainder of the way without using additional fuel.

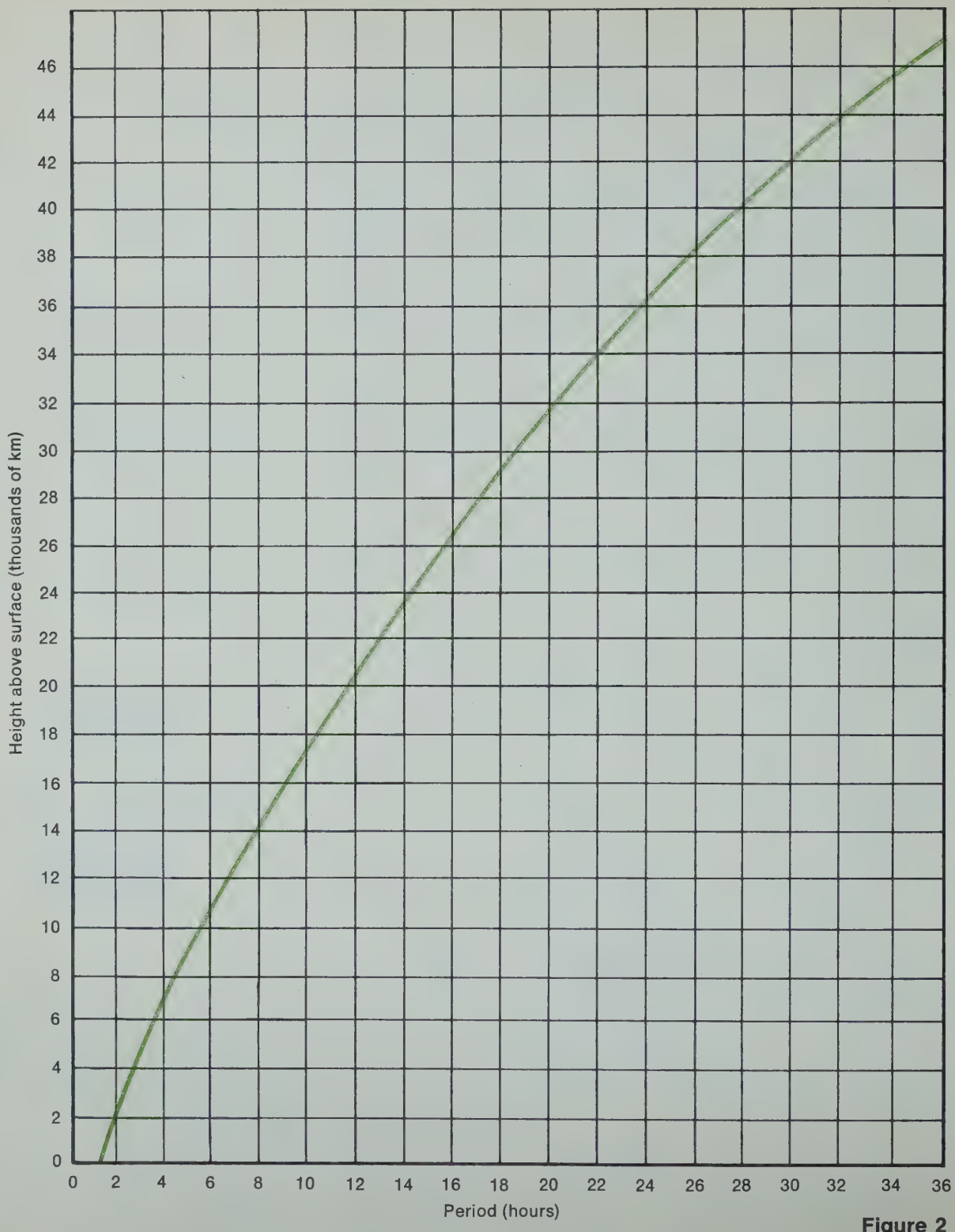
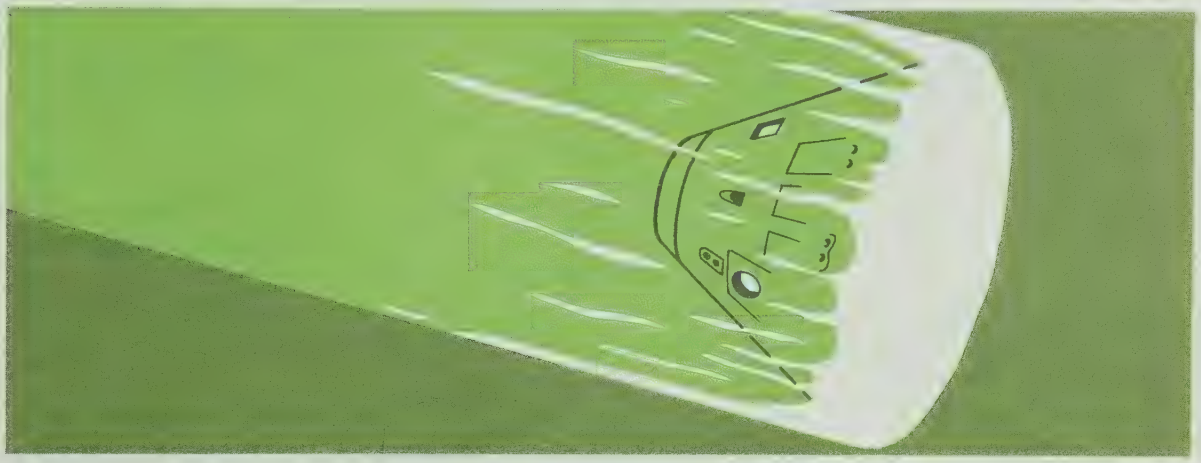

Height above surface (thousands of km)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
Period (hours)

Figure 2

Whenever a solid melts (changes to liquid), or a liquid boils or evaporates (changes to a gas), heat must be involved. For example, heat must be added to ice to change it to liquid water. Much more heat must be added to the liquid water to change it to steam.

Space travel makes use of this heat-absorbing behavior of substances. When a space capsule returns to the earth's atmosphere, friction due to contact with the air particles produces a huge amount of heat. You may have seen pictures of the charred surface of the spacecraft after its recovery in the ocean. The occupants, however, were unharmed. How can they have survived such a hot ride?



In the early days of space exploration, scientists learned about the dangers of reentry heat. They knew they had to come up with a way to offset the effects of this great heating. They decided to coat one side of the capsule with a solid material that would melt and then boil. If this melting and boiling could absorb most of the reentry heat, the rest of the capsule would be safe. They knew that what was needed was a substance that absorbed a lot of heat as melting and boiling took place. A substance was found, and it was used to coat the heat shield of the capsule. Now, on space flights, as this substance melts and boils away, it removes the excess heat due to friction. This heat-removal process is known as *ablation*—a surgical term that means "removal."

You can see how ablation works by doing an activity. You may want to do this activity at home, where you can use the freezer compartment of your refrigerator. Ask your teacher to lend you a thermometer to take home with you.

Excursion 4-4

Losing Heat

EQUIPMENT LIST

1 thermometer
2 paper clips*
1 small paper cup*
1 candle

Note: Starred (*) items must be furnished locally. In addition, the use of a freezer compartment is required, so the excursion may best be done at home.

This is a general-interest excursion.

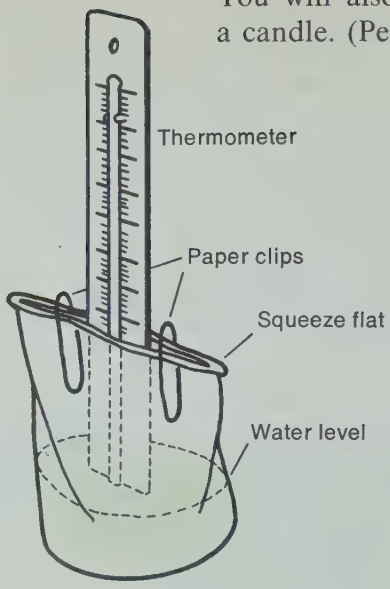
PURPOSE

To show one method that is used to dissipate the large amount of heat generated in a spacecraft upon reentry into the atmosphere.

MAJOR POINTS

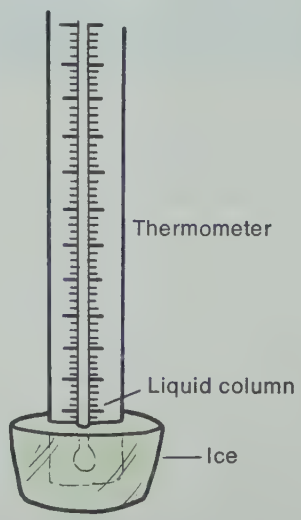
1. It is often desirable to study the variables involved in a complex situation by using a simpler situation involving the same variables, in which the variables being investigated can be more easily manipulated and measured. An example of this is the use of the thermometer-ice system to study the variables in the process of ablation in spacecraft.
2. It takes heat to change a substance from a solid to a liquid or a liquid to a gas.
3. A spacecraft, upon reentry, encounters a great deal of friction and uses a heat shield to absorb a large amount of heat. A special coating on the shield is melted and boiled away by the heat to protect the spacecraft's occupants.

You will also need a small paper cup, 2 paper clips, and a candle. (Perhaps you have some of these at home.)



ACTIVITY 1. Put about 50 ml of water in the cup. Set the thermometer in the center of the cup. Squeeze the top of the cup flat to the thermometer, and use the paper clips to hold it. Be sure that the bulb is in the center and covered with water. Put the cup in the freezer compartment overnight.

Sizes of paper cups vary. It is impossible to know what size is being used, and therefore the amount of water could also vary. Enough water should be used so that the thermometer bulb is completely covered.

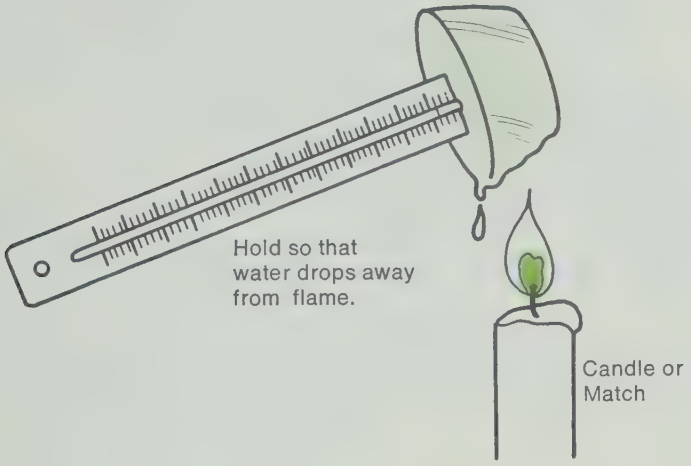


ACTIVITY 2. Check in the morning to be sure that the water is frozen. Carefully strip off the paper cup. The thermometer bulb should remain inside the ice, but the liquid column should be visible. Read the temperature. Then record it as your answer to question 1.

☐**1.** What is the temperature of the ice?

1. Depending on the freezer compartment setting, it is possible that the temperature of the ice is well below 0 °C. But it can't be above 0 °C and still be ice.

Now think of the ice coating on the thermometer as representing the heat shield of the space capsule. The thermometer itself can represent the men in the capsule. You now need a source of heat to represent friction. The candle, or some other flame, will do.



ACTIVITY 3. Hold the ice over a candle or match flame. Be careful not to let the flame hit the thermometer. Also, do not melt the ice enough to let the flame hit the bulb. Continue reading the thermometer as the ice melts.

☐**2.** Did the temperature rise as the ice melted?

☐**3.** What happened to the heat from the flame?

2. A Yes answer is possible here. If the temperature of the ice was significantly below 0 °C when the heat was applied, it will rise to 0 °C as melting takes place. The important thing is that it cannot rise above 0 °C until the ice is melted.

Of possible interest, but not important for the student, is the fact that the amount of heat used to melt the ice (assuming 50 ml of water was frozen) was 4000 calories. This is enough heat to raise the same amount of water 80 °C.

Be sure to return the thermometer to your teacher. Plastics and ceramics (like pottery) have been used as the ablative material on spacecraft. Apollo 12 used a brazed stainless-steel honeycomb with an outer layer of phenolic epoxy resin. (This resin material is similar to the substance that is often used to glue materials together.)

As the capsule entered the atmosphere, it left behind it a meteorlike trail of glowing liquid and gaseous material. Very little heat entered the spacecraft. The heat was carried away, just as the melting ice carried the heat away from the thermometer by changing first to liquid water, then to steam. In this way the astronauts were protected.

Creating Craters

CHAPTER EMPHASIS

After examining earth craters formed by various causes, and experimenting with the formation of craters in sand and bentonite, students develop a model for the formation of craters and rays on the moon

5

EQUIPMENT LIST

Per student-team

1 aluminum pan
1 sheet of newspaper
1 small steel ball
1 metrestick
1 light bulb and socket
1 metre of thread
1 glass marble
1 piece light-sensitive paper
Opaque objects
1 piece tape

Per class

Sand
Bentonite powder
Rottenstone
Lunar map

Excursion 5-1 is keyed to this chapter, and Excursion 4-1 is re-keyed

MAJOR POINTS

1 The moon and its features have always held a fascination for man
2 Specific generic names have been given the moon's features: e.g., mares (seas) and rays (streaks), emanating in all directions from specific spots on the surface
3. Many of its features bear the proper names of scientists, philosophers, and discoverers.
4 The origin of the moon's surface is of particular interest to scientists They believe it may help explain the age and origin of the earth
5 Model building (both mental and physical) is used in attempting to reconstruct the moon's history and explain its surface features
6 Physical models, like all other models, are approximate and have limitations When the limitations are apparent, models change, e.g., the shift from sand to bentonite to represent the moon surface
7 The model for crater formation is investigated one variable at a time, e.g distance of fall (speed) and then mass of the falling object
8 The effect of the incident light angle on the appearance of moon craters helps in building a moon-surface model
9 The process of making indirect measurements is used to determine the relative speed of impact objects
10 The energy of an impacting object, and the size of the resulting crater, depends on (a) the mass of the object and (b) the speed at which it hits

Until the time of Galileo, people thought the surface of the moon was smooth. They believed the pattern of dark areas on the moon's surface was like a stain or tarnish (Figure 5-1).

Figure 5-1

11. Comparison of moon and earth craters aids in inferring the moon's history.
12. Both meteorite impact and volcanic activity seem to have had a role in forming the moon's surface features.
13. The model used in judging the relative age of moon features involves judgments based on observations of impact overlaps and variable coloration of the moon's surface.

When Galileo looked at the moon through his telescope, he decided the surface was not smooth. He believed the shadows and light spots were valleys and mountains similar to those on the earth. He thought the large dark areas were water.

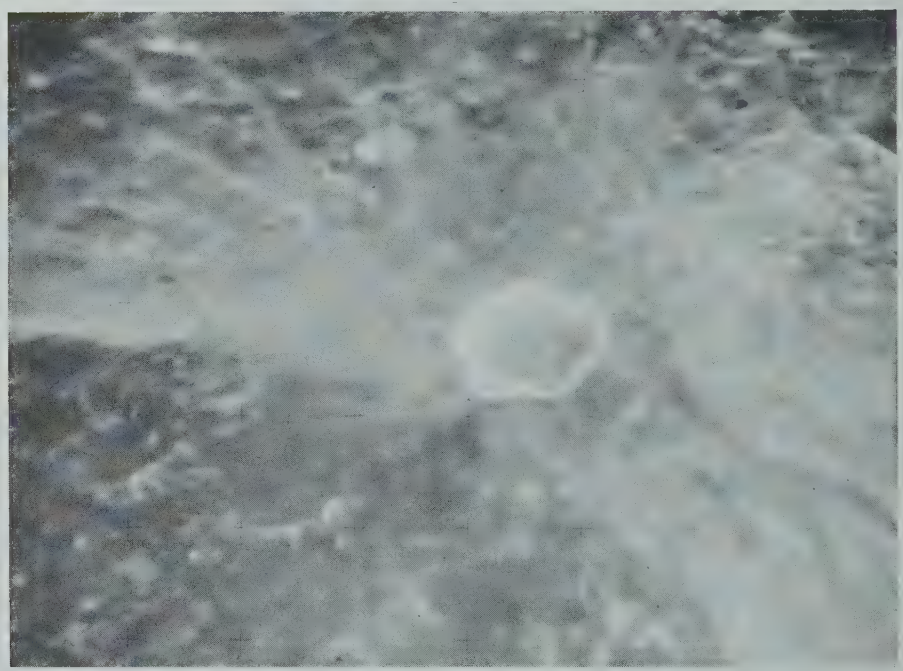
In Galileo's day, scientific writing was done in Latin. The Latin name for sea is *mare* (pronounced "mah'-ray"). This

Students may have to be encouraged to put a little extra effort into the examination of the photographs in this chapter. There is a tendency to just take a quick look and then go on. It will help if they will try to match up the moon photograph with the corresponding feature on the lunar map.

word is still used on many charts of the moon today. The Apollo 11 astronauts landed on Mare Tranquillitatis (in English, the Sea of Tranquility).

Galileo also saw shapes that looked like the craters of volcanoes. Some of these had long, light-colored streaks radiating from them far out over the surface of the moon. The streaks became known as rays. Some of the craters were given names. They were named for famous men, like Galileo, Copernicus, and Kepler (Figure 5-2).

Figure 5-2



In question 5-1 below, the most common student answer will probably be Yes. People in general have a distorted conception of the height of mountains in relation to a horizontal scale. A little simple arithmetic will illustrate the true relationship. Suppose the earth appeared the size of a bowling ball from far out in space. The tallest mountain, Everest, is about 9 km high. The diameter of the earth is about 12 800 km. A bowling ball is about 22 cm in diameter. So 9 km/12 800 km equals X cm/22 cm. X, the height that Mount Everest would appear on the bowling-ball-sized earth, equals 0.015 cm. This is only 0.15 mm, or less than the width of a pencil line. It would be extremely difficult to see the mountains sticking up. To put it another way, if the earth with its highest mountains and deepest trenches were reduced to the size of a bowling ball, it would be about as smooth and as perfect a bowling ball as was ever manufactured.

Few people who looked at the moon from the earth could see the things that Galileo described. One of the difficulties with looking at a surface from far away is that it is so hard to see features as they really are. Everything seems flat.

There are some very tall mountains on the moon. Some are as high as the tallest earth mountains. Distance has a great effect on how high they appear to be.

☐**5-1.** If you were to look back at the earth from far out in space, would you be able to see the height of its mountains?

Figure 5-3 shows an astronaut's view of a moon mountain.

Hopefully, students will realize, even before a point is made of it in the text, that the mountains (as well as other features) are visible mainly because of the shadows

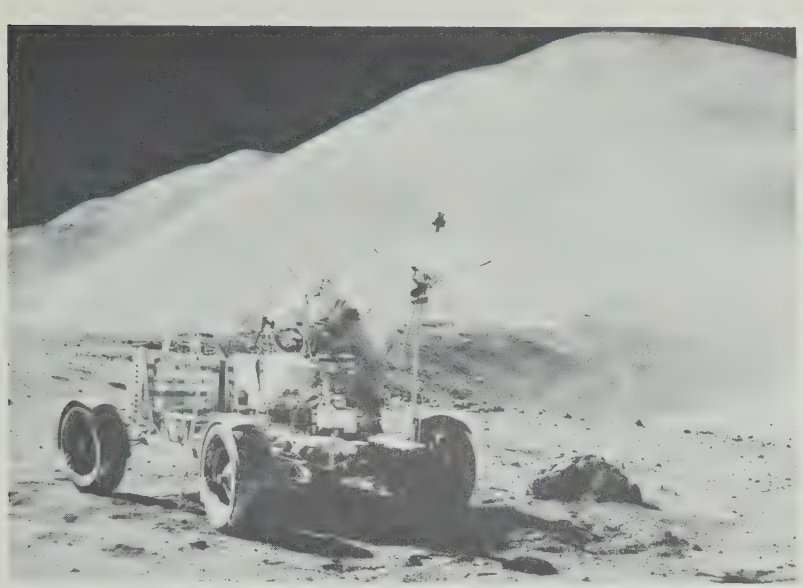


Figure 5-3

A great deal has been learned about the moon since Galileo's time. More photographs, plus rocks and soil, have been sent back from orbiting satellites and brought back by men who have been there. Of course there are still many things to be learned (Figure 5-4).

Figure 5-4

You or your students may have other and better questions about the moon than these listed here. The five given, and others, could serve as a good takeoff point for small-group discussions.

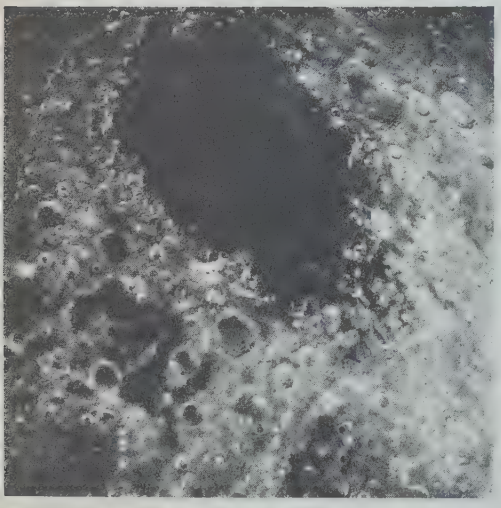
Scientists are particularly interested in finding out how the moon's surface became as it is. In fact, they are concerned with how the moon came into being and how its age is related to that of the earth. Other questions about the moon might include these:

1. Did the moon start as a hot, melted globe of matter, which then cooled down?
2. Was the moon once a part of the earth—a fragment that became separated from it long ago?
3. Was the moon built slowly out of pieces of material that came together as they moved through space around the earth and the sun?
4. Has the moon always been cold and airless?
5. Were there ever any volcanoes there?

For the rest of this module, you will be studying some surface features of the moon. Some comparisons will be made with earth features. These comparisons and some activities may help you explain how the moon's surface got the way it is.

Begin your study by examining some moon and earth photographs. Figures 5-5 through 5-8 show craters and mountains on the moon.

Figure 5-5



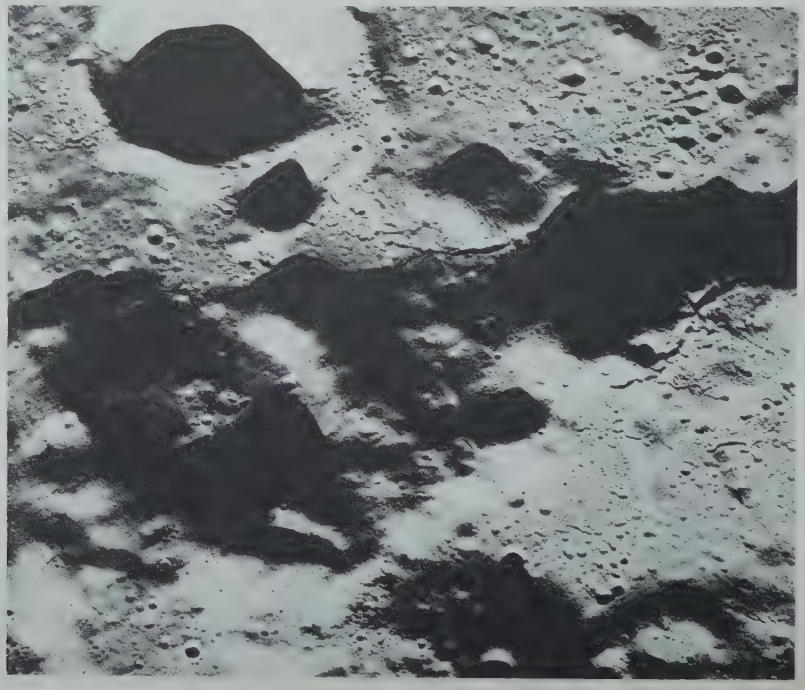


Figure 5-6

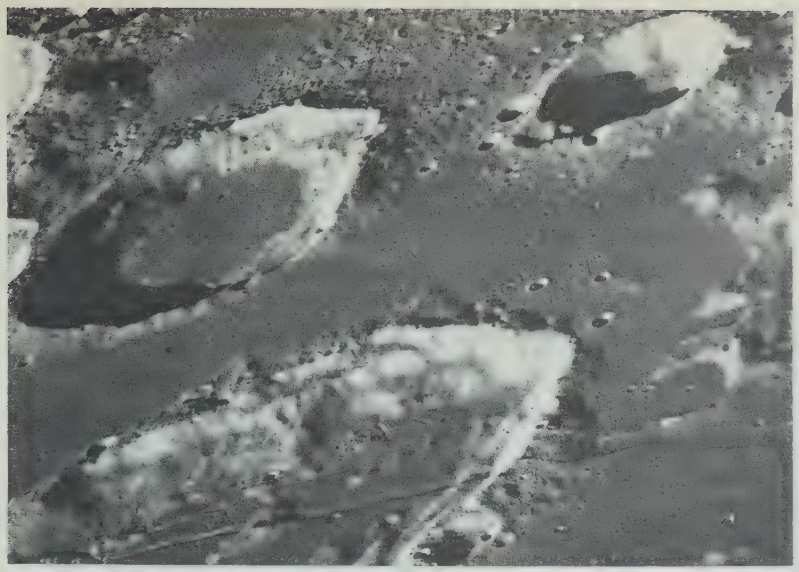
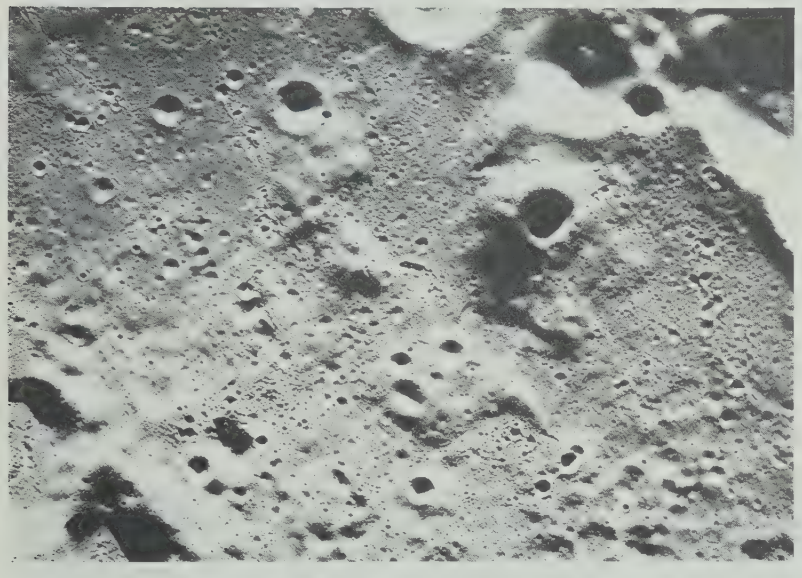


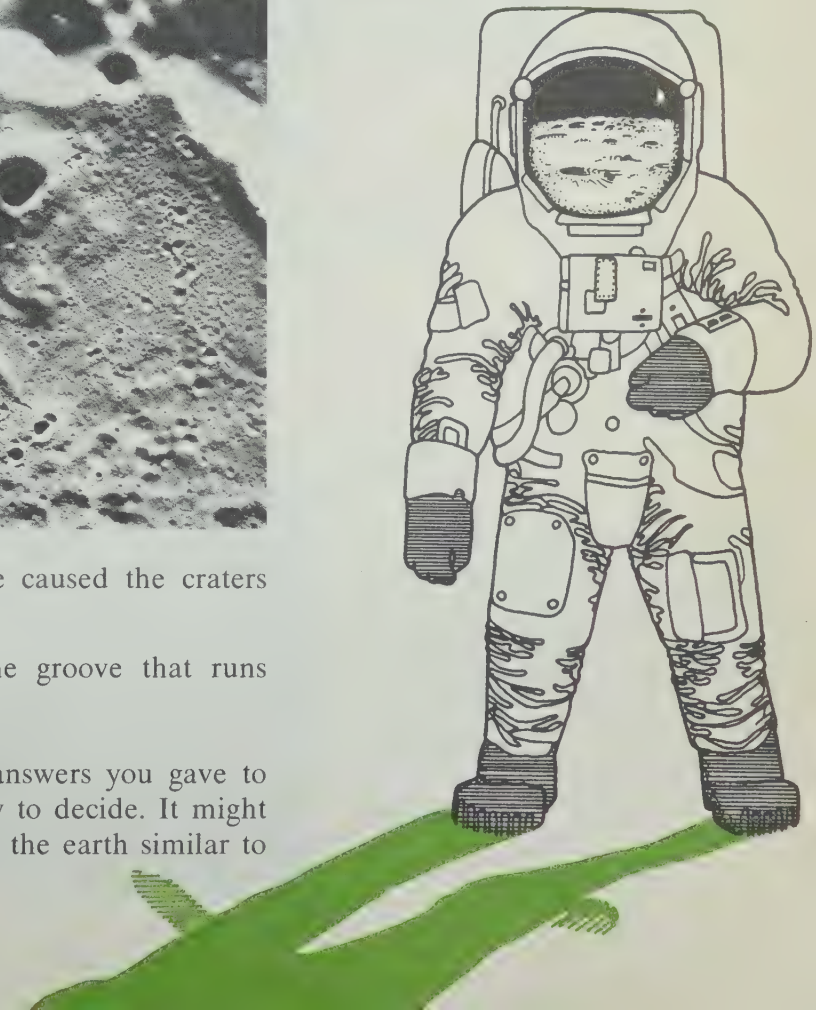
Figure 5-7

This is another photograph taken by the Apollo 8 astronauts. The crater has a network of cracks, or rilles, on the floor. The prominent one running horizontally across the picture cuts through the crater rim and other features, so it must have formed after the crater. It is believed the rilles were caused by cracking of the moon's crust and the subsequent settling of the surface.



The cone-shaped mound has a small crater in its top. Scientists believe formations such as this one might have been caused by volcanic activity on the moon. The surrounding surface has some of the characteristics of lava flow found on the earth (Figure 5-8).

Figure 5-8



☐**5-2.** What do you think could have caused the craters shown in Figures 5-6 and 5-7?

☐**5-3.** What might have produced the groove that runs through the crater in Figure 5-7?

You probably had reasons for the answers you gave to questions 5-2 and 5-3. But it's not easy to decide. It might help to be able to examine features on the earth similar to the ones shown, if there are any.

There are various kinds of craters on the earth. You know what a crater is—it's like a bowl-shaped hole. In the following photographs, you will have the opportunity to examine some of these bowl-bottomed holes. As you do, see if you can spot the differences in them. Perhaps this will help you later, when you examine similar features on the moon's surface.

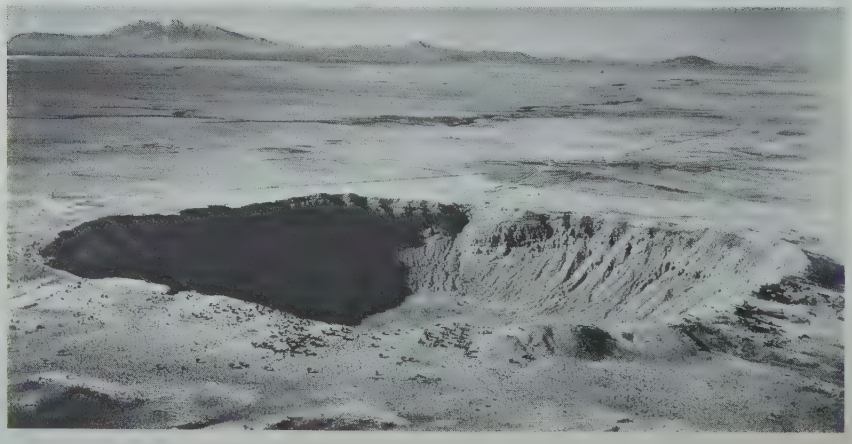
Many cinder cones, with craters in the top, can be found on the earth. This one is in Lassen Volcanic National Park. Note the related lava flows. Also notice that there is a double cone (Figure 5-9), which shows that the volcano erupted twice from the same vent.

Lassen Volcano is one of the few on the North American continent that still shows some volcanic activity. It has erupted violently in this century, and although it is now dormant, gases and steam still issue from several fissures. The cinder cone pictured here is close to the main volcano, and was formed in the not too distant past as a result of a secondary eruption, with lava flowing and cinders piling up.

Figure 5-9

Meteor Crater near Winslow, Arizona, has a raised rim. Metallic fragments have been found around the rim. The floor of the crater is about 150 metres below the surrounding ground. There are no other features like it in the immediate vicinity (Figure 5-10).

Figure 5-10



Meteor Crater has been called Arizona Crater, Winslow Crater, Canyon Diablo Crater, Coon Butte, and Crater Mound, among other names. It is one of the best known and most widely studied features of its kind on the earth. From rim to rim it is about 1200 metres in diameter. The nickel-iron fragments were so plentiful that at least one man staked a mining claim to the area. It is estimated to be about 25 000 years old.

This active volcano in Alaska has a well-defined crater. The cone was built by former eruptions, but only steam and gases are sent out now (Figure 5-11). Note the characteristics of a volcanic crater: (a) a small crater located at the top of a roughly circular cone; (b) the floor of the crater higher than the surrounding area; (c) steep outer slope; and (d) lava flows associated with it.

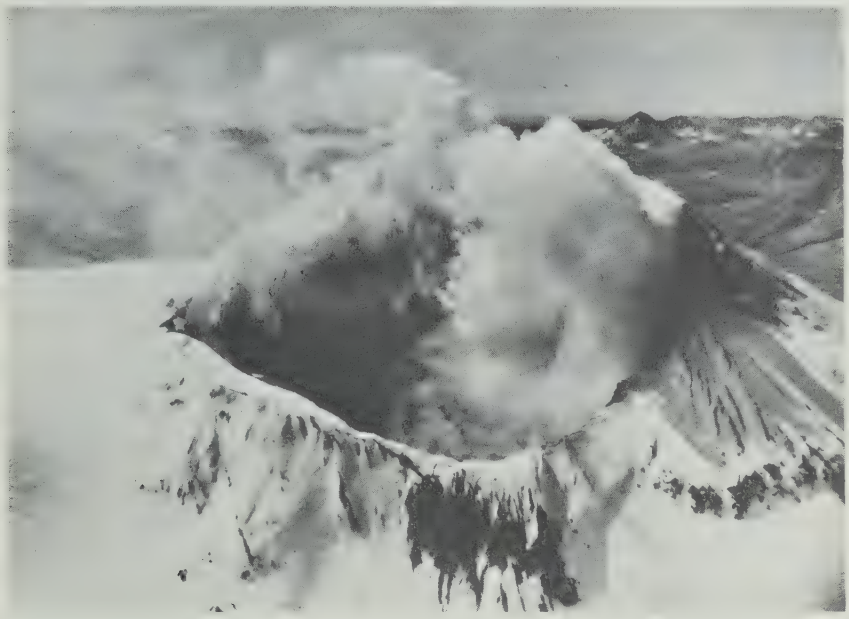


Figure 5-11

Volcanic craters like this one are small in comparison with the large impact craters that have been shown. But the cone itself has often been built up much higher than those of impact craters. There are still many active volcanoes in the world.

Wolf Meteorite Crater in Australia was discovered in 1947. Notice the raised rim. The floor is below the level of the surrounding terrain (Figure 5-12).

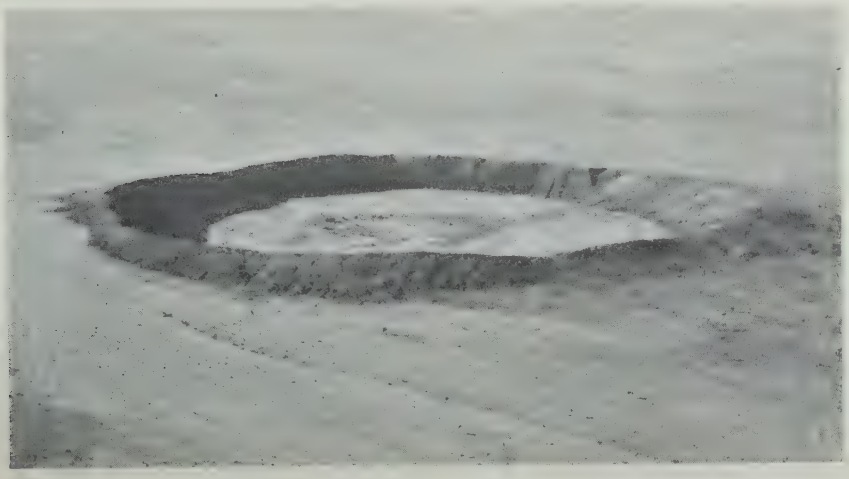
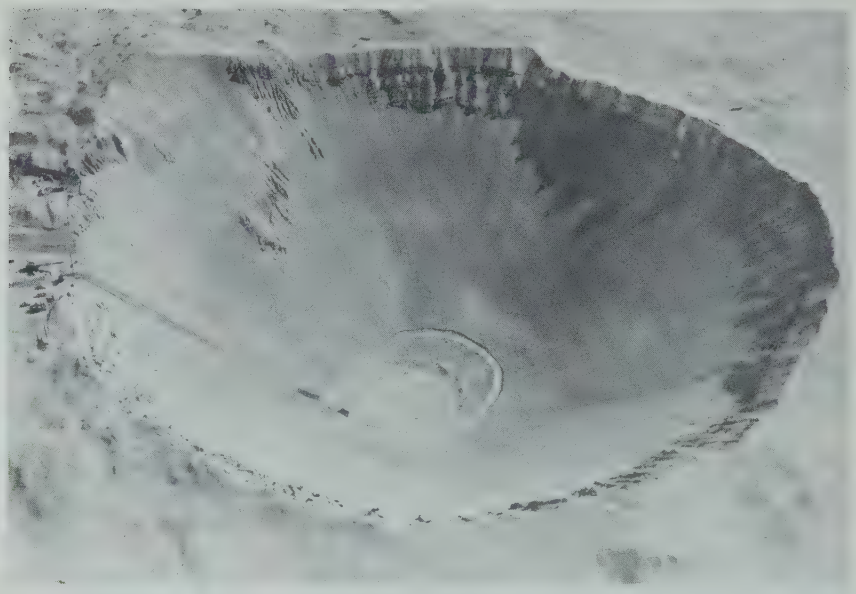


Figure 5-12

At least 14 craters caused by impact have been identified on the surface of the earth. This one is in such a remote area that its discovery from an airplane was fairly recent. There may have been many others, which have been obliterated by wind and water erosion, vegetative processes, or civilization.

An underground atomic blast was set off at a test site in Nevada. The resulting circular hole is about 365 metres in diameter. Notice how material was thrown out. The crater walls are quite sloping instead of vertical (Figure 5-13).

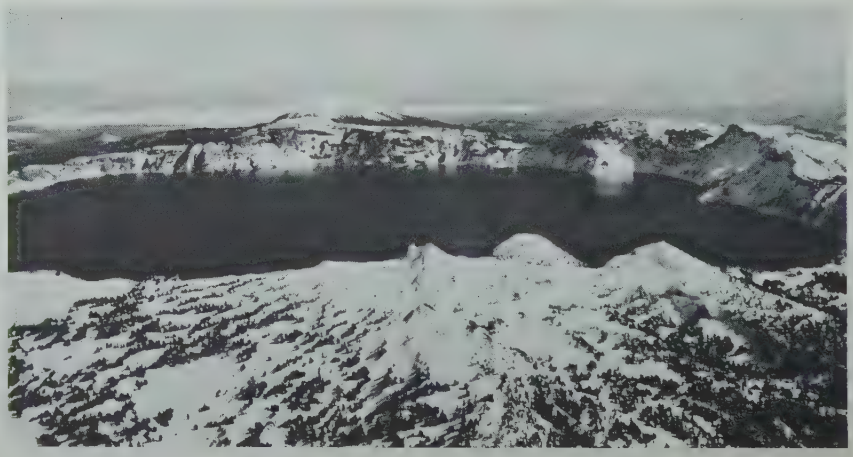


Because of the terrific heat, a considerable amount of material is vaporized in a blast of this kind.

Figure 5-13

This is Crater Lake, a national park in Oregon. After erupting centuries ago, the upper half of the volcanic mountain collapsed into the center, forming a huge pit that filled with water. Just over the rim can be seen the flat-topped cone of Wizard Island, a newer volcano that arose from the old shell (Figure 5-14). You can imagine that the shape of the cone before its collapse was something like the one that can be seen in the distance.

Figure 5-14



The collapse of an entire mountain is one example of sinking (subsidence) of the earth's surface. On a much smaller scale (and with a different cause) are the sink holes found in various parts of the world.

What you've learned by examining features on the earth can help you as you observe pictures of craters on the moon. Perhaps you can develop your own model of how these craters were formed. If you want to know more about how models are developed, read over **Resource 12,** "Model Building." For instance, the presence of certain materials around the rim of the Meteor Crater has caused scientists to believe this crater and others on the earth were caused by meteor impact. Now you see why it is called Meteor Crater. Some of the fragments are metallic. It is believed these fragments could only have come from outer space. In addition, some materials were finely powdered and broken up, as if by a powerful blow. Look again at Figures 5-9, 5-10, 5-11, and 5-12.

☐**5-4.** Which of these would you classify as impact craters? as volcanic craters?

Let's summarize the differences you can see in the two types of craters:

1. Volcanic craters are much smaller than impact craters.
2. The floor of an impact crater is lower than the surrounding area. The floor of a volcanic crater is higher than the surrounding area.
3. A volcanic crater generally has a steeper outer slope.
4. Volcanic craters generally have lava flows coming from them.

At first glance, moon craters most nearly resemble meteor craters on the earth. Figure 5-15 shows a moon crater, Figure 5-16 an earth meteor crater.

Figure 5-15

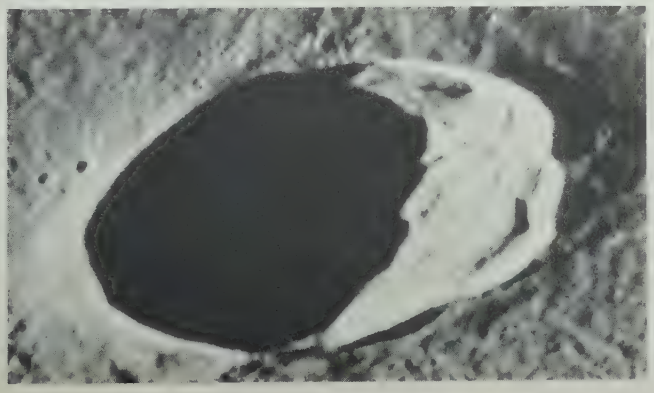
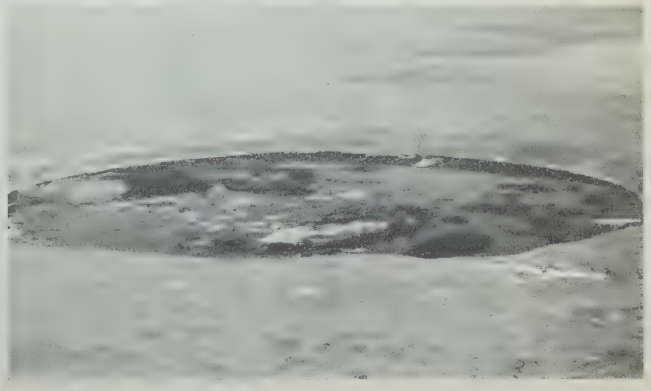


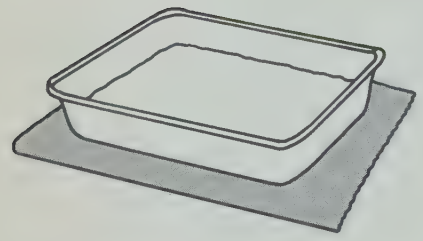
Figure 5-16



You need to see for yourself how craters like these are formed. Remember, however, that a real meteor striking a surface would be traveling at a very high speed. Your activity can only approximate what would really happen if a high-speed meteor struck the moon's surface. You will need the following equipment:

Insist on the newspaper on the floor for sand and bentonite activities throughout the module. Also, urge students to pour any splashed material back into the appropriate pan. Note that sand packs down quite easily, and when packed, it behaves quite differently upon impact of an object. Have students repour the sand frequently from one pan to another.

2 aluminum pans
1 sheet of newspaper
1 small steel ball
1 metrestick
Sand
1 floodlight or unshaded bulb
1 small glass marble
1 metre of thread
Tape

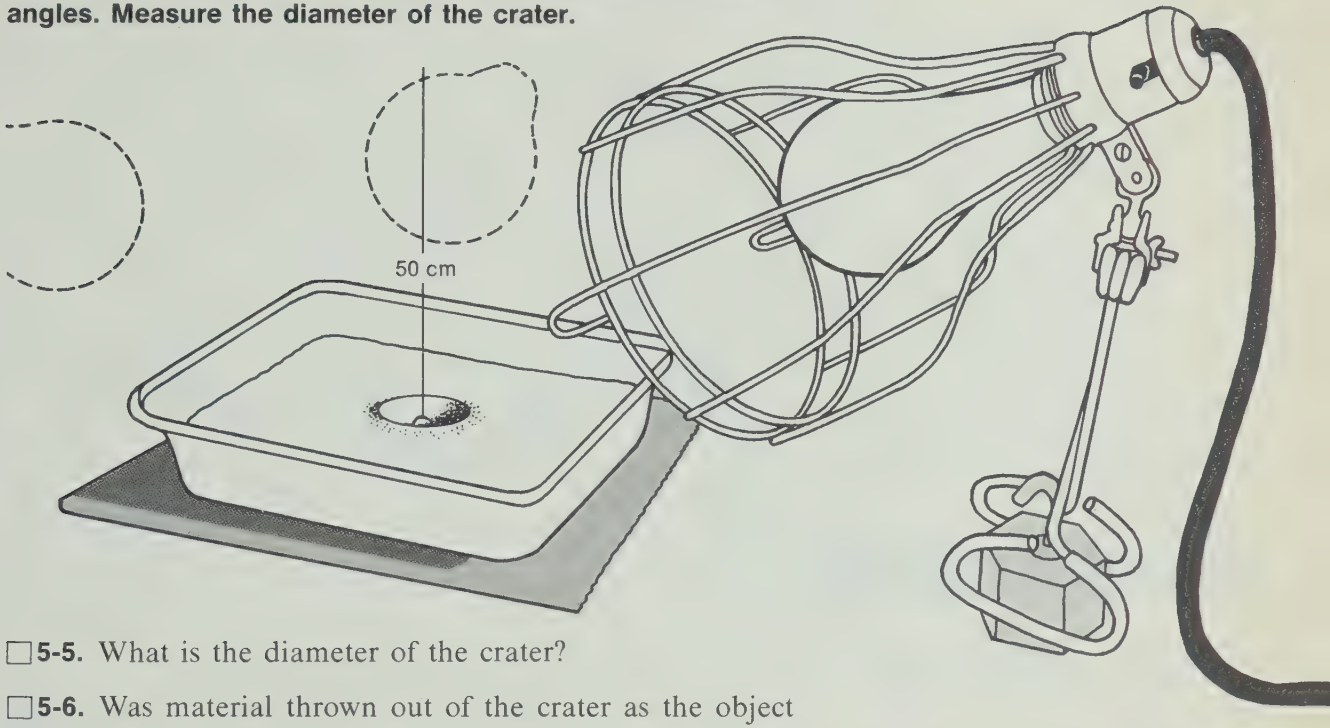


ACTIVITY 5-1. Lay the sheet of newspaper on the floor. Place one pan in the center of the newspaper. Pour sand into the pan to a depth of about 3 cm. Smooth the sand with your hand, but do not shake the pan or pack the sand down. Packed sand behaves quite differently upon impact of an object. So pour the sand from one pan to another after each impact.

ACTIVITY 5-2. Attach the thread to the ball with a small piece of tape.

ACTIVITY 5-3. Hold the ball 50 cm above the sand. Leave some slack in the thread so that when you release the ball, it won't be jerked back.

ACTIVITY 5-4. Drop the small steel ball into the sand from the 50-cm height. Gently lift the ball straight up out of the sand. Then examine the crater that was formed. Use the floodlight to illuminate the crater from the side at different angles. Measure the diameter of the crater.



☐ **5-5.** What is the diameter of the crater?

☐ **5-6.** Was material thrown out of the crater as the object hit?

☐ **5-7.** Is there a raised rim around the crater?

☐ **5-8.** Is the floor of the crater below the level of the surrounding surface?

☐ **5-9.** How many times greater is the diameter of the crater than the diameter of the ball?

When the ball hits the sand, it does work on it to move it out of the way. To do work, a body must have energy.

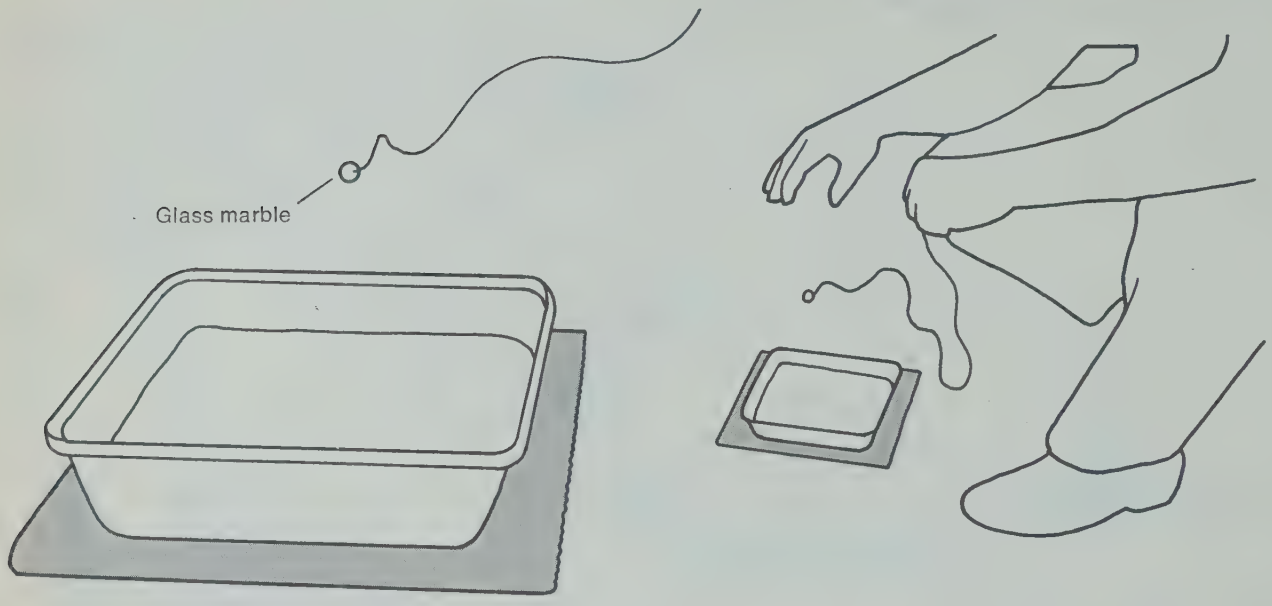
From your past experience, you may recall that the energy of a body in motion depends on its mass (the quantity of matter) and its speed (how fast it is traveling). You can test the effect of these factors by varying them, one at a time, and measuring the diameter of the crater formed. First, try changing the mass. You have already used the steel ball, so now you can use the glass marble.

5-5. About 4 cm (Because of differences in sand, it is impossible to predict the exact diameter.)

These five questions are aimed at identifying the most easily discernible features of impact craters: (a) roughly circular in shape, (b) material thrown out onto surrounding area, (c) raised rim, (d) floor below the level of surrounding surface, (e) ■ size relationship between crater and impacting body.

Here the energy of the impacting object is being equated to the diameter of the crater formed—in other words, to the volume of sand moved. The energy is really not that simple to measure. Some of it is converted to heat. However, the student should be able to get the concept that the diameter of the crater is some indication of the energy of the body.

ACTIVITY 5-5. Pour the sand into the other pan. Smooth out the sand, but do not pack it down. Drop the glass marble from the same 50-cm height. Remove the marble and measure the diameter of the crater.



☐**5-10.** What is the diameter of the crater?

☐**5-11.** Compare the size of the crater formed by the glass marble with that formed by the steel ball.

5-10. About 3 cm (Once again, differences in sand can change the exact measurement.)

5-11. The size formed by the glass marble should be smaller than that formed by the steel ball. (However, students may incorrectly expect that the diameter with the glass will be only half as much. The volume of the conical crater varies as the cube of the diameter; 4^3 is 64 and 3^3 is 27. The volume of the steel-ball crater is therefore a little more than twice the volume of the glass-marble crater, which is as it should be. The student, of course, is not expected to know this cubic relationship.)

The mass of the steel ball is more than twice that of the glass marble. Although you could not measure how much, you probably noticed that more sand was removed by the impact of the steel ball.

Next, try varying the speed. Two simple rules will help you in making this test.

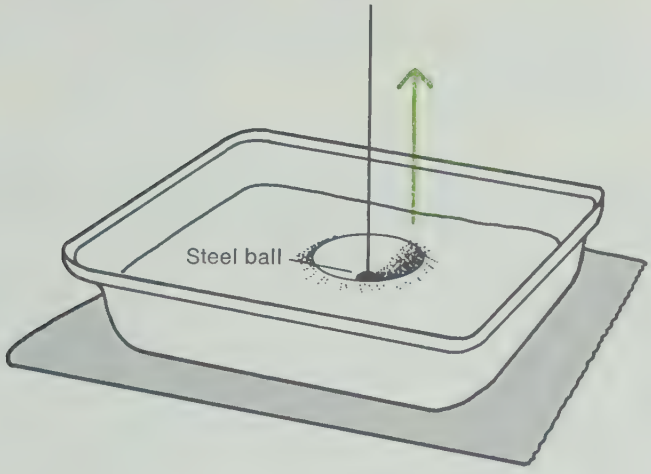
1. Objects of the same size when dropped from the same height fall at the same speed, no matter how heavy they are. **Excursion 4-1,** "Time to Fall," should help you understand this statement.
2. A body hits at a greater speed if it is dropped from a greater height.

Rule 1 means that the steel ball and the glass marble fell at equal speeds in Activities 5-4 and 5-5. Rule 2 will enable you to test the effect of speed on crater formation.

EXCURSION

Excursion 4-1 is a good general-interest excursion that could be also considered remedial in helping with the behavior of falling bodies. It was first keyed in Chapter 4.

ACTIVITY 5-6. Pour the sand into the other pan. Smooth out the sand again, but do not pack it down. Drop the steel ball into the sand from a height of 1 m. Measure the diameter of the crater after removing the ball.



☐ **5-12.** What is the diameter of the crater?

☐ **5-13.** Compare the size of the crater formed by dropping the ball from 1 m with the one formed by the 50-cm drop.

The steel ball hits at a greater speed when dropped from 1 m than when dropped from 50 cm but not twice as great. However the volume of the conical crater should be about twice as great with a 1-m drop. With the volume varying as the cube of the diameter, it would be reasonable to expect a diameter of about 5 cm for the 1-m drop of the steel ball (question 5-12). This would mean that the volume of material moved would be in the ratio of 125 to 64 (5 to 4^3), or roughly 2 to 1. In question 5-13, however, the student will note only that the crater formed by the higher drop is larger.

Your investigation should have shown that both the mass of the object and its speed have an effect on the size of the crater that is formed. Most meteors that have been studied are composed of generally similar materials. They were not as different as your steel ball and glass marble. Therefore, an increase in mass would mean a meteor of greater diameter.

You probably found that the diameter of the crater was about three times greater than the diameter of the steel ball. You probably also found that the diameter of the crater increased by about $1\frac{1}{2}$ times with an increase in the speed of the object (caused in this case by the greater height from which the ball was dropped). Meteors hit the surface of the earth at enormous speeds. Geologists estimate that the diameter of the crater formed is usually about 20 times the diameter of the meteor!

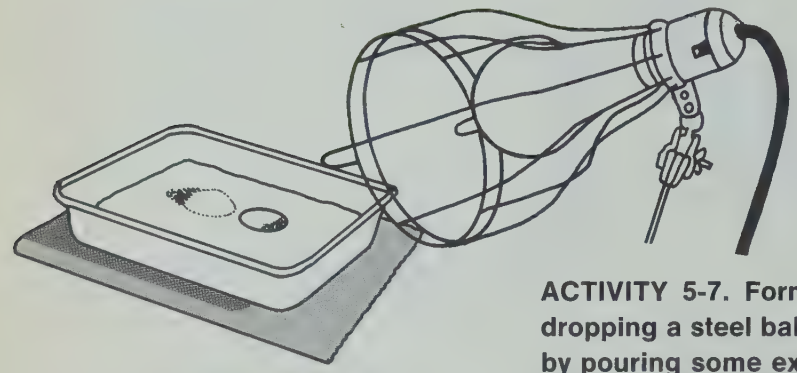
It would be possible for a body to hit the earth in a head-on collision with a speed of over 40 km per sec. A meteorite 60 m in diameter, as the one that caused the 1200-m-diameter Meteor Crater in Arizona might have been, would have a mass of over a billion kg. Traveling at 40 km per sec, it could have over a billion billion newton-metres of energy—more than a sizable H-bomb.

☐ **5-14.** If the meteor crater is about 1200 metres in diameter, what do you predict was the diameter of the meteor that created it?

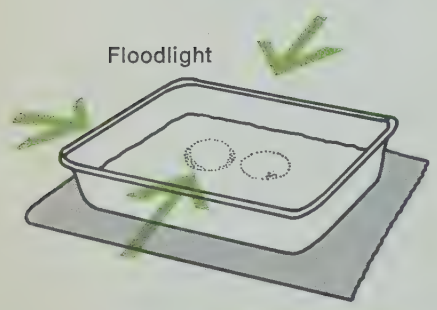
In 1908 a body, believed to be a small comet, exploded as it reached the ground in upper Siberia. Luckily, the event occurred in a desolate, uninhabited forest. The surrounding trees were flattened for 60 km in all directions. People were blown over and window glass broken at a distance of 160 km. The pressure wave created by the blast affected barometers in England, a continent away. The head of the comet, composed of dust and frozen gases, probably had a mass of about a billion kg and was traveling at a tremendous speed.

An object so large and traveling at a high speed must have created a blast like an atomic bomb. The terrific heat generated by the energy of impact vaporized part of the earth's surface and part of the meteor. Perhaps you noticed the similarity of the crater formed by the underground atomic blast (Figure 5-13) and the Arizona, Australia, and Quebec craters. Scientists believe impact explosions made them all look somewhat alike.

You will be investigating other kinds of surface features shortly. But perhaps you would like to know why the floodlight was used to illuminate the craters you formed. The next activity will show you the reason.

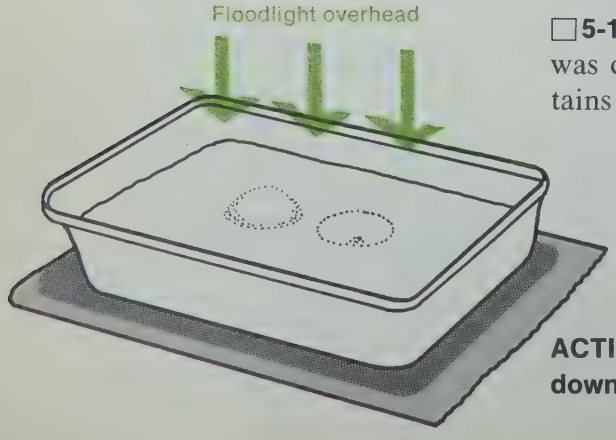


ACTIVITY 5-7. Form another impact crater in the sand by dropping a steel ball. Close to the crater, make a circular hill by pouring some extra sand onto the surface. Light the area from the side with the floodlight.



☐**5-15.** Describe the appearance of the hill and the crater when lighted from the side.

ACTIVITY 5-8. Move the floodlight to each of the other three sides of the pan. Observe the changes in the position of the shadow.



☐**5-16.** How could you tell from which direction the light was coming if you saw a photograph of craters and mountains with shadows?

ACTIVITY 5-9. Move the floodlight so that it shines straight down on the hill and the crater.

☐**5-17.** In what way did a change to overhead lighting change the appearance of the features on the sand surface?

Observers of the moon have found that they can tell much more about the features if the light comes from the side. The depths of craters and heights of mountains are more clearly defined than with lighting from above. The following figures illustrate this.

Both Figure 5-17 and Figure 5-18 are pictures of the large crater Tsiolkovsky on the far side of the moon. It was first photographed very roughly from the Russian spacecraft Lunik III in 1959. Since that time it has been shot in finer detail by cameras on the Lunar Orbiters and by several Apollo missions. The other craters that can be seen in Figure 5-17 have not been named.

Figure 5-17

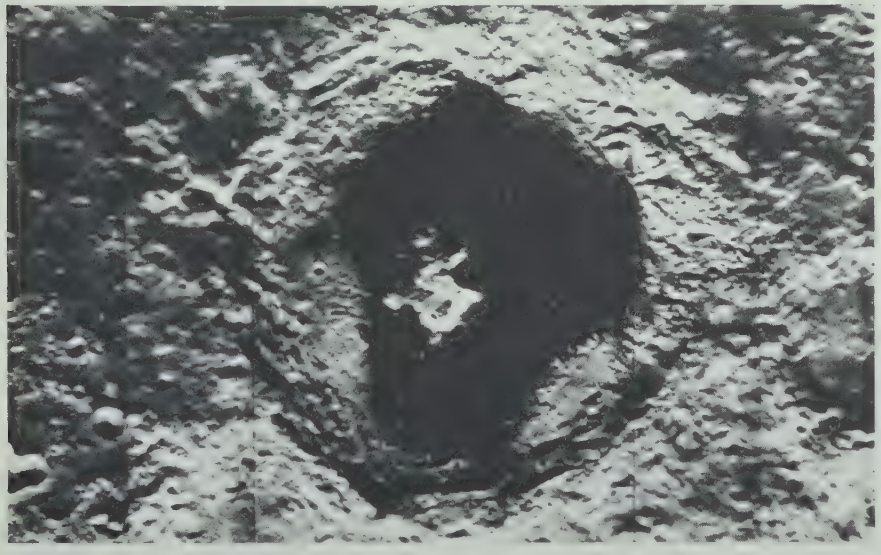


Figure 5-18

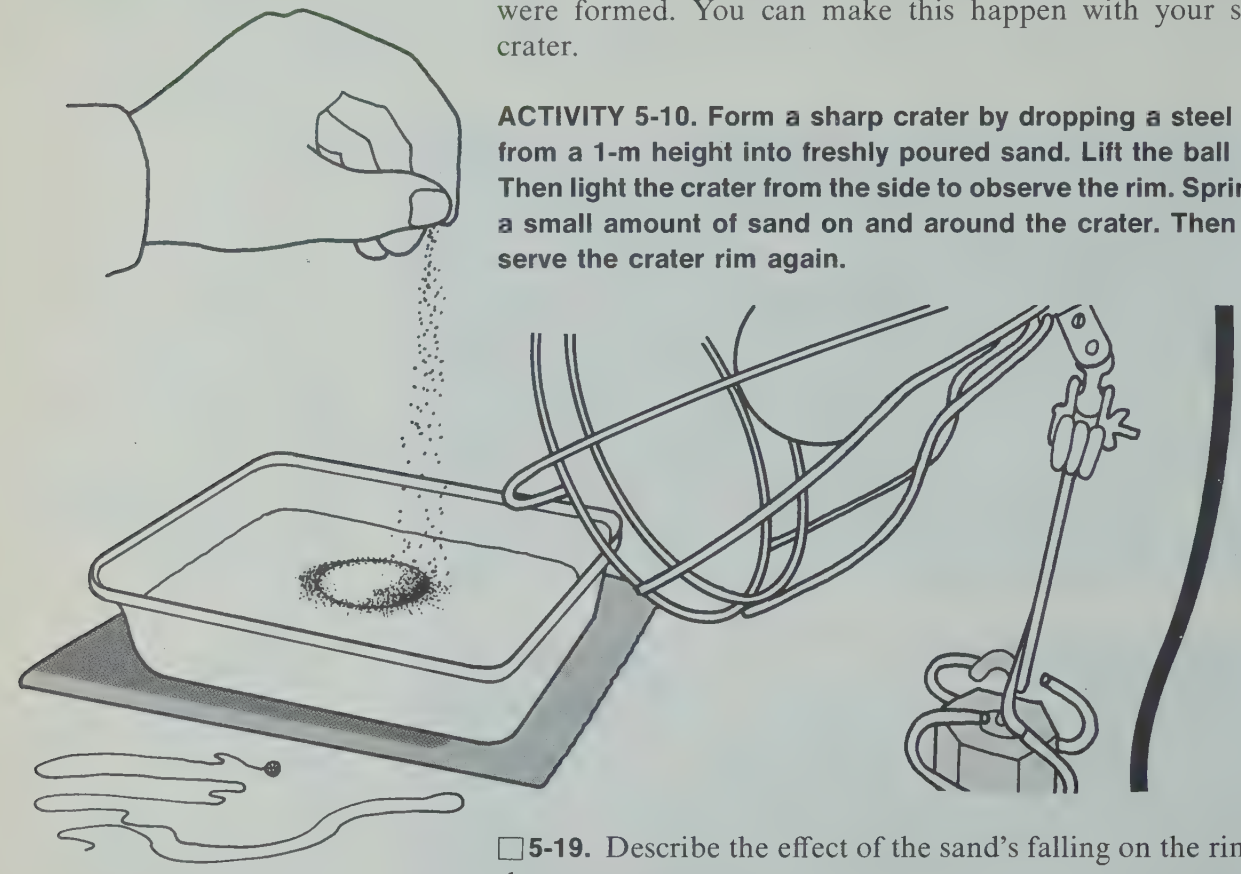
Both photos are of a large crater on the far side of the moon. Figure 5-17 was made with the sun overhead. Figure 5-18 had the sun shining from one side. Notice how the details show up in Figure 5-18.

5-18. From below (This is from the west in the photograph, which has been turned 90° for ease of printing.)

☐**5-18.** From which direction was the light coming in Figure 5-18, above or below?

Many craters on the moon do not have sharp rims. They look as if they have been worn down or eroded since they were formed. You can make this happen with your sand crater.

ACTIVITY 5-10. Form a sharp crater by dropping a steel ball from a 1-m height into freshly poured sand. Lift the ball out. Then light the crater from the side to observe the rim. Sprinkle a small amount of sand on and around the crater. Then observe the crater rim again.



☐**5-19.** Describe the effect of the sand's falling on the rim of the crater.

There is no weather on the moon's surface. That is, there is no rain, snow, or wind. With no weather, you would expect the surface to stay sharp and clean. But scientists believe the moon is constantly bombarded by particles from space.

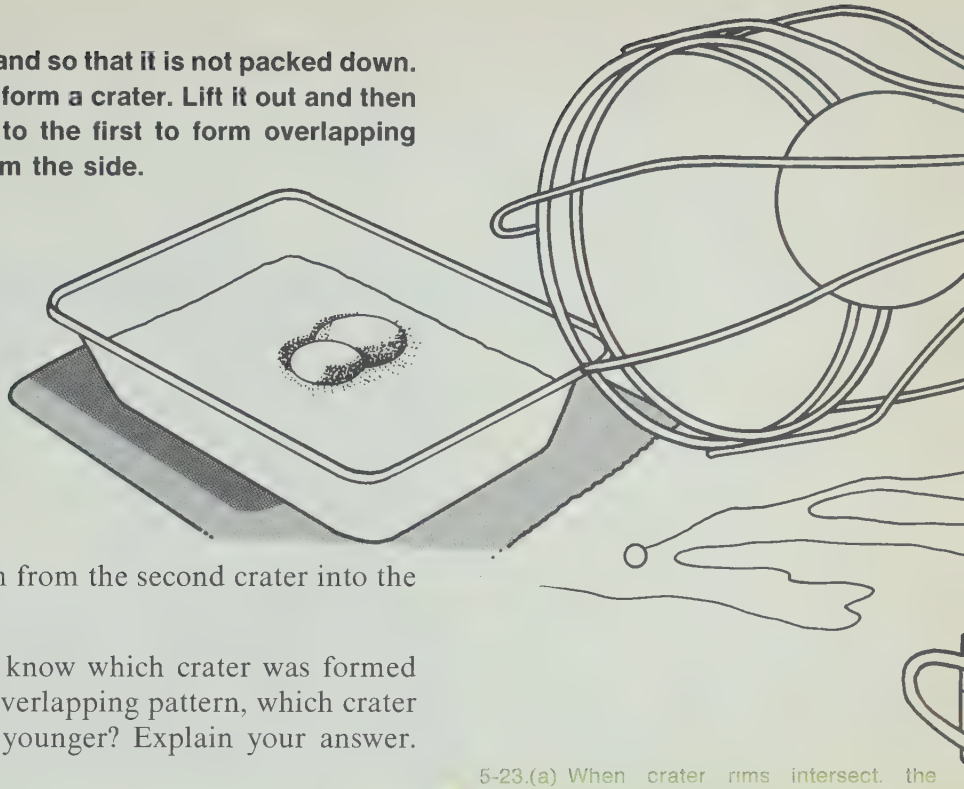
With no atmosphere to slow the particles from space, or to burn them up as the earth's atmosphere does, all the cosmic dust reaches the moon's surface. The earth, with its greater gravitational attraction, collects perhaps a billion kg of space dust a year; the moon, then, must collect a huge amount as well.

☐**5-20.** How would constant bombardment of small particles affect the sharpness of the moon's features?

☐**5-21.** Suppose a large object struck the surface near a crater. What do you predict would happen?

Now check your prediction.

ACTIVITY 5-11. Repour the sand so that it is not packed down. Drop a steel ball from 1 m to form a crater. Lift it out and then drop it again close enough to the first to form overlapping craters. Light the craters from the side.



☐**5-22.** Was material thrown from the second crater into the first?

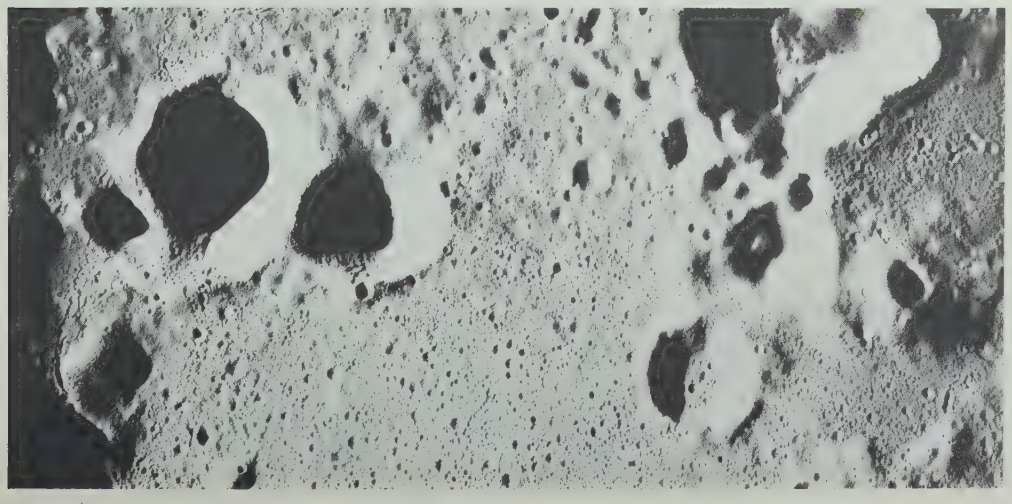
☐**5-23.** Suppose you didn't know which crater was formed first. Could you tell, by the overlapping pattern, which crater is the older and which the younger? Explain your answer.

5-23.(a) When crater rims intersect, the younger rim will tend to be complete and the older rim will be interrupted by the younger. (b) The younger crater will often displace material from the old rim into the old crater. (c) Younger craters have sharper rims. (d) When one crater is within another, the inner crater is assumed to be younger.

Figure 5-19

PROBLEM BREAK 5-1

The moon photograph in Figure 5-19 shows several craters and hills. Make a rough sketch similar to Figure 5-20 in your Record Book. Identify the hills with a small h and the craters with a small c. If you can identify the overlapping craters, put a 1 on the one that was formed first. Put a 2 on the one that came next, and a 3 on the youngest one.



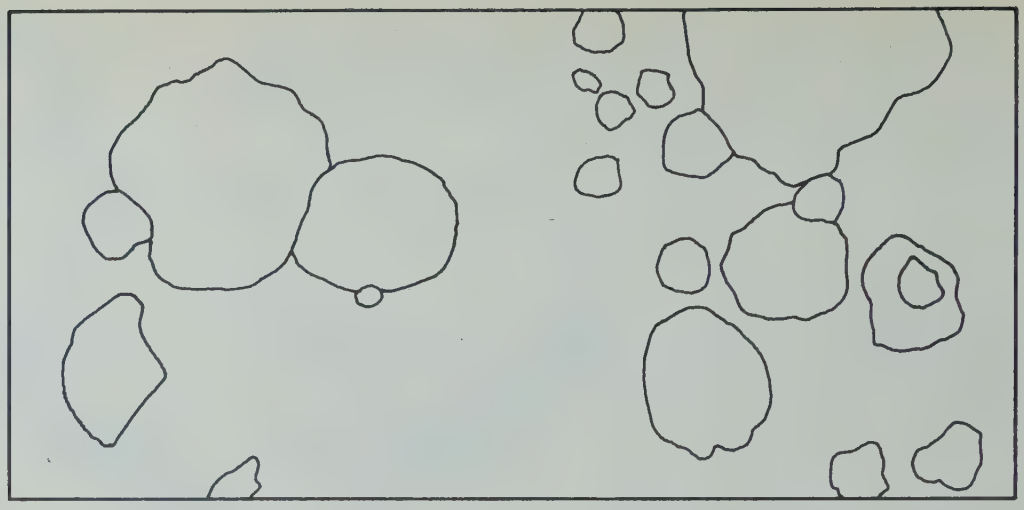
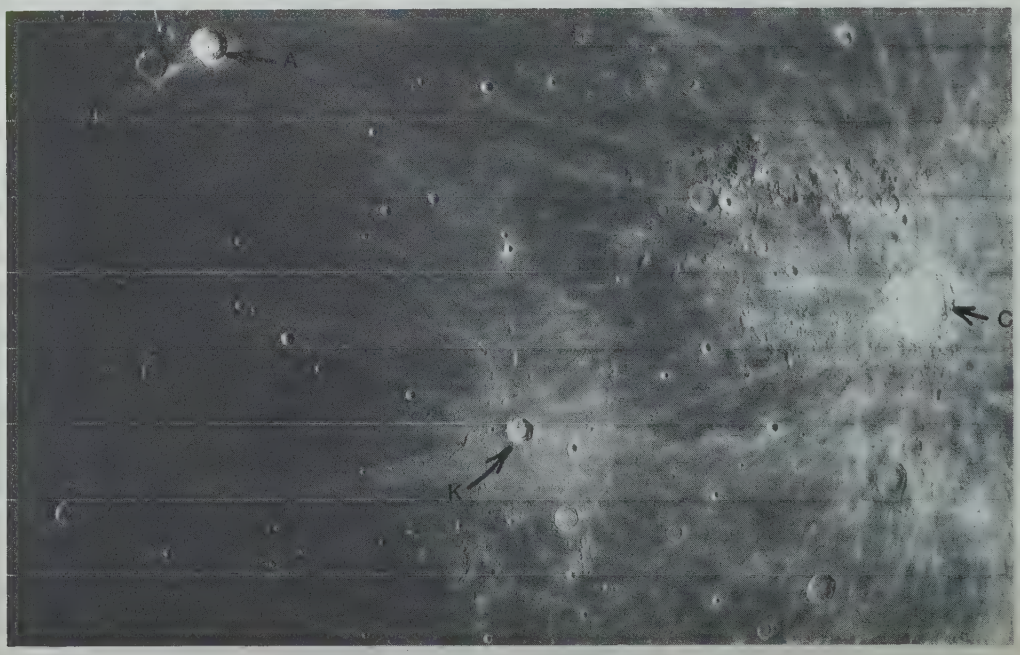


Figure 5-20

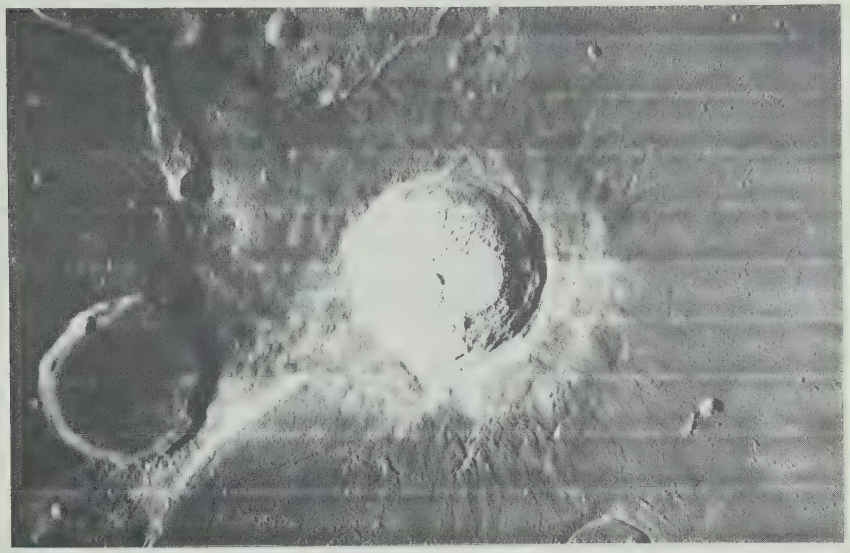
Compared with other moon craters, Copernicus is probably average in size, but it is still a large feature. It is about 90 km in diameter and 3840 m deep. This means that its walls, from the floor to the top of the rim, are comparable in height to mountains on the earth.

Galileo and other scientists who studied the moon long ago saw that some craters looked very different from others. Streaks of light-colored material seemed to branch out from them. One of the best known groups of these craters is shown in Figure 5-21. The large crater Copernicus (C) is at the right edge in the photograph. Kepler (K) is to the left of Copernicus, just right of center. Aristarchus (A) is to the left of center and above Copernicus and Kepler. The horizontal lines are due to the way the photograph was made.

Figure 5-21



You probably noticed that the streaks, which are called *rays,* go out from the crater like spokes of a wheel. They cross the dark surface areas and other craters. A closer look at part of the area might help. Figure 5-22 is a closer view of Aristarchus, showing the rays in more detail.



The tendency to be dogmatic about the causes of various features on the moon should be avoided. Very little is actually known about the moon's surface. The students are being asked to make inferences on the basis of their examination of similar features on the earth, and on activities they are performing on a much smaller scale. For example, the material that forms the rays is thought to have come from beneath the surface. This presumes that this "splashed" material is lighter than the surface material. But all craters do not exhibit these rays even though material must have splashed out of all of them. The model for crater formation on the moon assumes that some factors must be working to darken the surface material. Then the craters that have rays or light-colored halos must be younger because the material has not had the time to be darkened. This is just a model. There may be other forces or factors operating on the moon that are not known at this time.

Figure 5-22

Figure 5-23 is a still closer look at Aristarchus. Notice what appear to be ripples in the surface material.

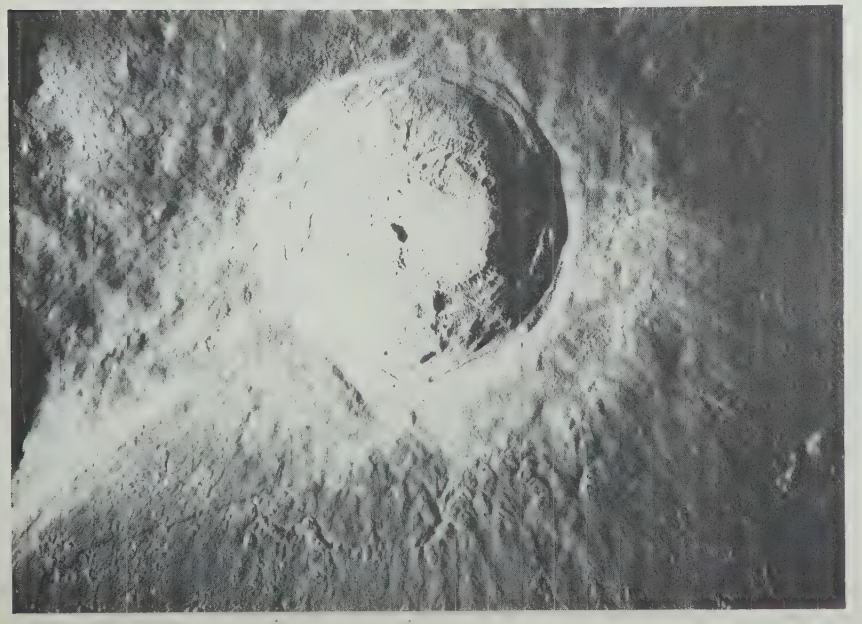


Figure 5-23

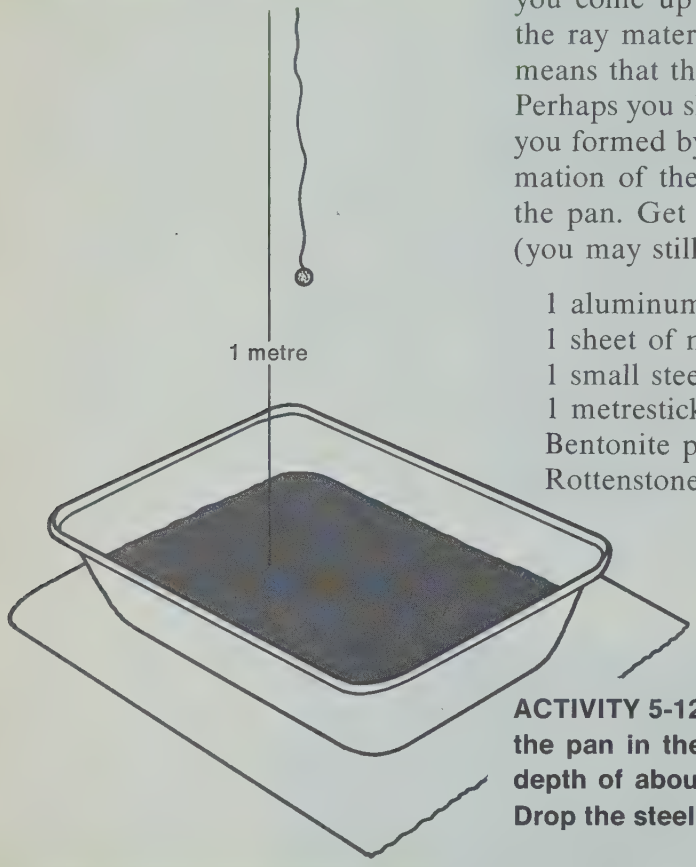
☐**5-24.** Where do the materials that form the rays seem to have come from?

☐**5-25.** Why, do you think, are the rays lighter colored than the surrounding area?

Question 5-25 is difficult. But a little thought might help you come up with a good answer. You probably said that the ray materials seem to have come from the crater. This means that they came from below the surface of the moon. Perhaps you should make a closer examination of the craters you formed by dropping the steel ball. For a better approximation of the moon's surface, use a different substance in the pan. Get any of the following materials that you need (you may still have the first four items):

1 aluminum pan
1 sheet of newspaper
1 small steel ball, with thread attached
1 metrestick
Bentonite powder
Rottenstone

The fine powder called bentonite that is used here is an interesting substance. It was originally found near Fort Benton, Montana; hence the name. It is really a powder ground from rock called montmorillonite, which is fairly common and widespread on the earth. The rock is made up of a mixture of types of clay and is considered to be of volcanic origin.



When water is added to the powder, it swells up and becomes rather gelatinous and slippery. In this form it is used as driller's mud in oil well drilling. It also serves as a filler and plasticizer in soap and paint, as a suspending agent in pharmaceuticals, and as a carrier in agricultural chemicals. It can be used repeatedly for the cratering activities if care is taken to keep it uncontaminated.

The bentonite, unlike the sand, will work better if it is settled and packed a little. Jar the pan several times by lifting either end about one-half inch from the floor and letting it drop. You may want to experiment with the procedure ahead of time, and possibly modify it. This should be done each time the bentonite is used.

ACTIVITY 5-12. Spread the newspaper on the floor, and place the pan in the center. Pour the bentonite into the pan to a depth of about 2 cm. Jiggle the pan to settle the bentonite. Drop the steel ball from 1 m, observing the crater as it forms.

☐**5-26.** Was material thrown out of the crater?

☐**5-27.** Did it form a ray system of a different color than the surface?

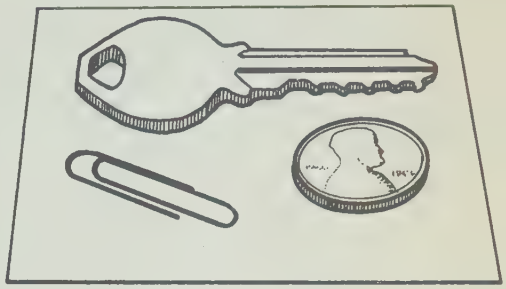
Apparently, something happened on the moon to cause the material on the surface to be darker than the material under the surface. The same thing did not happen with the bentonite. What could have darkened the surface of the moon?

You know that the moon has no weather conditions as we know them on the earth, and it has no air.

With no atmosphere to cut down the light from the sun, the moon has much more intense sunshine. The radiation also lasts for a longer moon day. Could it be that the various rays from the sun have a darkening effect on the moon's surface? You can see whether they have a similar effect here on earth. You will need the following things:

1 square of light-sensitive paper (protected from light until ready for use)
Coin, key, and other opaque objects

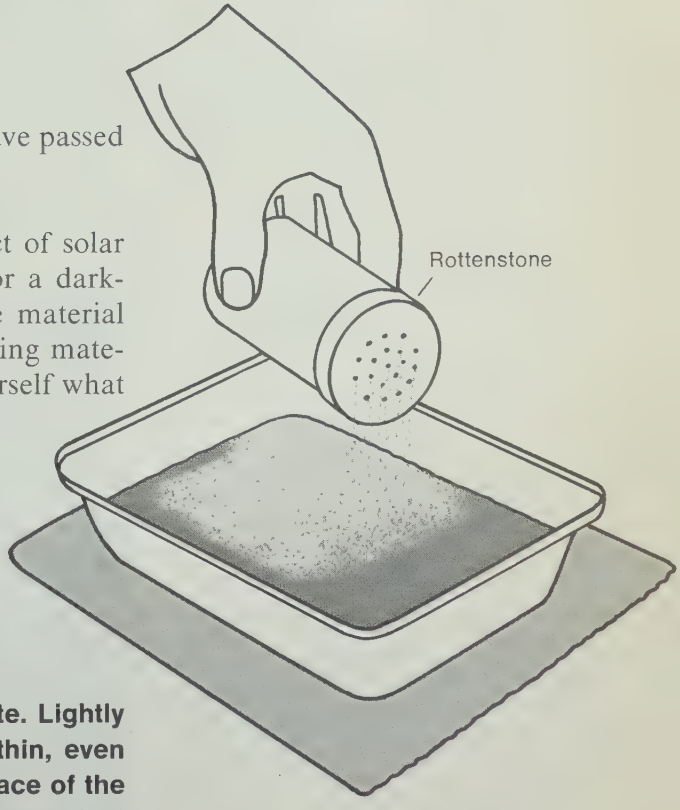
Students may question the statement that the radiation lasts for a longer moon day. They will find out, in Chapter 7, that a moon day is 29½ earth days long; half of this is bright sunlight, the other half is darkness.



ACTIVITY 5-13. Lay the light-sensitive paper on a window ledge or other spot where it can receive bright sunlight. If it is an overcast day, use the floodlight. Lay a key, a coin, and other objects on the paper. Let them remain for several minutes.

☐**5-28.** Describe the paper after several minutes have passed and the objects have been removed.

Light rays do darken some materials. The effect of solar radiation on the moon's surface might account for a darkening of the top layer. The top layer protects the material underneath from the sun's rays. Thus, the underlying material should be lighter in color. You can see for yourself what happens when a meteor strikes such a surface.



ACTIVITY 5-14. Smooth the surface of the bentonite. Lightly shake the rottenstone over the surface so that a thin, even layer is formed. This dark layer represents the surface of the moon, darkened by solar radiation. Now drop the steel ball from a 1-m height.

☐ **5-29.** Describe your observation of the crater that formed.

☐ **5-30.** Do the rays that are formed resemble the ones from certain craters on the moon?

The light-colored streaks from some of the rayed craters on the moon extend for great distances. The relatively young crater Tycho in the southern highlands has a ray system that stretches half way around the moon. And probably everyone remembers the Apollo 16 astronauts Young and Duke exploring the brightly rayed craters called North Crater and South Crater in the Descartes highlands.

The rays on your model of the moon's surface probably don't extend very far. The ones on the moon seem to continue for very long distances. Some thought about the conditions on the moon as compared with those on the earth should help to explain this difference.

☐ **5-31.** How does gravity on the moon compare with that on the earth?

☐ **5-32.** How would air resistance on the moon compare with that on the earth?

EXCURSION

Excursion 5-1 is a short remedial and general-interest excursion. It requires no equipment. It suggests another activity that can be done by students, and is described in a teacher note in your edition.

If you are not sure of your answers to the last two questions, try **Excursion 5-1,** "Less Force."

It is believed that when large meteors hit the moon and formed craters such as Aristarchus, Copernicus, and Kepler, many pieces of the meteors and of the moon were thrown out of the crater. The speed at which this material was thrown must have been tremendous. With no air resistance and much less gravity than on the earth, some of these particles left the moon and went into space. Some are known to have been captured by the gravity of the earth.

Figure 5-24

If you look closely at the rays extending from the crater Kepler, you can see they consist of many small craters (Figure 5-24). Each of these is surrounded by ejected dust. This dust sometimes forms in dunes like sand dunes on the earth.

Sand dunes on the earth are formed by the movement of sand by water or air.

☐ **5-33.** Are dust dunes on the moon formed in the same way as the sand dunes on the earth? Explain your answer.

Apparently many of the large craters on the moon were formed by meteors. This does not mean that other things, like volcanic action, could not have formed craters. There may be examples of other kinds of craters in areas that you have not yet examined. Remember your observations of features on the earth and compare them with the moon's features. You'll probably agree with scientists that meteor impact was a major cause of the large holes in the surface of the moon.

Before going on, do Self-Evaluation 5 in your Record Book.

GET IT READY NOW FOR CHAPTER 6

You will need pieces of cardboard that must be supplied locally. The backs from used tablets will do fine. You also need baby-food jars, matches, sand, sheets of newspaper, and cellophane tape as additional local supply items.

This is a remedial and general-interest excursion.

Excursion 5-1

Less Force

EQUIPMENT

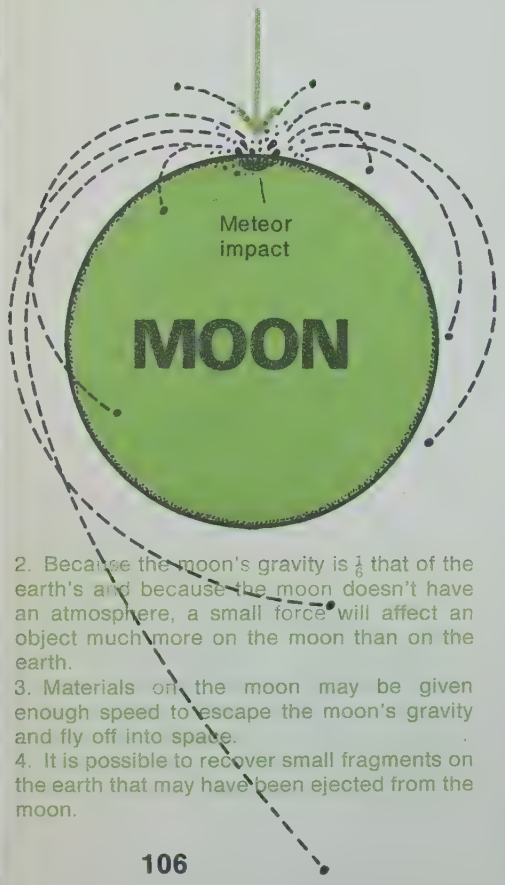
Magnifier or microscope
Piece of plastic wrap
Bar magnet
Tape
Spoon
Beaker or glass of water
Microscope slide
or piece of glass

PURPOSE

To examine the effects of decreased gravity and lack of atmosphere on objects in motion on the moon, and see how some of them escape lunar gravity.

MAJOR POINTS

1. The interaction of the variables mass and distance (lunar radius) produces a force of gravity on the moon that is $\frac{1}{6}$ of the earth's gravitational force.



2. Because the moon's gravity is $\frac{1}{6}$ that of the earth's and because the moon doesn't have an atmosphere, a small force will affect an object much more on the moon than on the earth.
3. Materials on the moon may be given enough speed to escape the moon's gravity and fly off into space.
4. It is possible to recover small fragments on the earth that may have been ejected from the moon.

The force of gravity that a body exerts depends partly on the mass of the body. It also depends on how far the center of the body is from whatever object it is attracting.

When both of these factors—mass and distance—are taken into account, the force of gravity exerted by the moon on objects at its surface is only $\frac{1}{6}$ as much as the force of gravity would be if the objects were on the surface of the earth. This means that you or your spacecraft would weigh only $\frac{1}{6}$ as much on the moon's surface as on the earth's surface.

☐**1.** What is your weight on the earth?

☐**2.** What would your weight be on the moon?

Because the moon's force of gravity is weak, it cannot hold an atmosphere. So there is no air on the moon. Thus, an object moving above the moon's surface would have no air friction to slow it down. The smaller pull of gravity and the absence of air friction have a great effect on the way objects move on the moon.

Suppose a big meteor, traveling at speeds up to 65 km per second, strikes the surface of the moon. Material is splashed out in all directions. Parts of the surface and of the meteor are melted or powdered. The force of the impact gives some pieces enough speed to take them halfway around the moon.

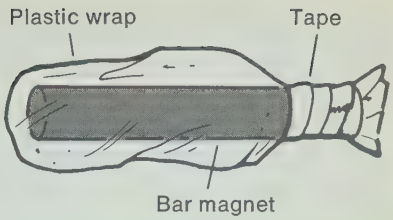
The speed of the material that is thrown out determines how far it will go. Some chunks go only a short distance. Then they hit the surface and may form other craters. Other pieces go great distances before hitting the surface. Some materials reach a speed high enough to escape the moon's gravity. These pieces shoot out into space.

☐**3.** What might happen to the pieces that shoot out into space from the moon?

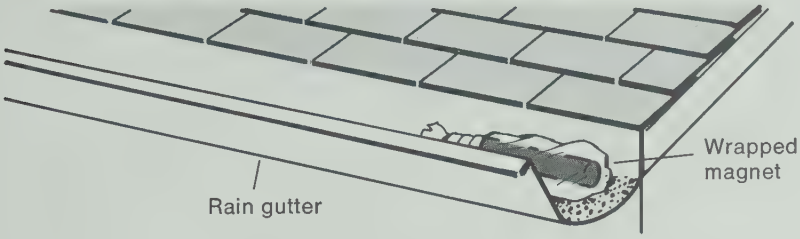
It's hard to know exactly what happens to all the pieces that shoot out into space. But some of them could be captured by the earth's gravity, and eventually reach the earth's surface. And there's a way you could find some of them. Here's how. You will need the following equipment:

1 bar magnet	1 piece of plastic wrap	Microscope slide
Tape	Beaker of water	or piece of glass
Spoon	Magnifier or microscope	

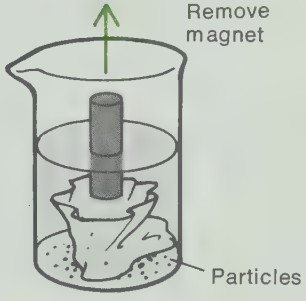
ACTIVITY 1. Wrap the bar magnet in a single layer of plastic wrap, and fasten it with tape.



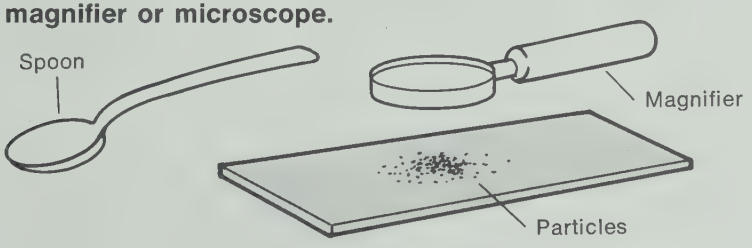
ACTIVITY 2. Drag the wrapped magnet through a rain gutter or catch basin where rainwater collects. Remove it from the water basin carefully, so the tiny particles clinging to it are not knocked off.



ACTIVITY 3. Immerse the wrapped magnet in a glass or beaker of clean water. Carefully remove the magnet from the plastic. The particles will fall to the bottom of the glass.



ACTIVITY 4. Use a spoon to remove some of the settled material from the glass or beaker. Put it on a microscope slide, piece of glass, or a clean piece of white paper. Examine it with a magnifier or microscope.



☐**4.** Describe the appearance of the particles.

If you found some small black spheres, they are mostly iron. Small light-colored spheres are a mixture of sand and iron. The iron in them causes them to cling to a magnet.

Comparison of the two kinds of small spheres with moon dust brought back by the astronauts shows that they are similar. Some of your particles may have come from the moon.

Materials have been found on the earth that have been identified as coming from outer space. Some, such as pieces called tektites, may even have come from the moon as a result of one of the large meteor impacts.

☐**5.** When the Apollo astronauts kicked moon dust with their boots, they noted that the particles went a long way before settling to the surface. How do you account for this?

Peaks and Flows

There are no excursions keyed to this chapter.

CHAPTER EMPHASIS

The formation of peaks, cones, and domes might be caused by fluid flow resulting from impact, volcanism, and uplifting. The relative ages of features on the moon can be inferred from their relation to each other

6

EQUIPMENT LIST

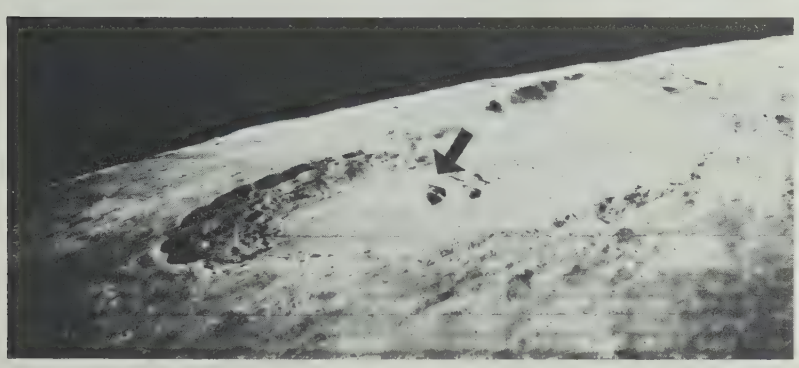
Per student-team

1 medicine dropper
1 glass or baby-food jar
1 piece of cardboard
Bentonite
Rottenstone
1 plastic straw
1 candle or burner
Matches
Sand in pan
1 sheet of newspaper
1 floodlight
1 balloon
Cellophane tape

MAJOR POINTS

1. Observations made while using a physical model based on hypothetical surface conditions during meteor impact (dropping water on a water surface and a bentonite surface) provide explanations for
   a. the formation of central peaks within lunar craters, and
   b the variation in height of peaks
2 Using observed features of volcanism (photographs) and a simple physical model (bentonite straw, balloon), the following conclusions are suggested
   a Some cones on the moon might be of volcanic origin
   b Volcanic action could explain rock debris on and around lunar cones
   c Volcanism may have deformed surface rock layers into dome-shaped mountains on the moon where magma couldn't reach the surface
   d Volcanism may have produced large lava flows, now called seas, on the moon where magma reached the surface.
3 In contrast to the model of modification of earth features by weathering, conclusions are drawn that lunar features may be modified over time by a "rain" of meteors.
4 It is possible to postulate the relative age of lunar features by the way they are related to other features

You have spent most of your time looking at holes in the surface of the moon. Perhaps you noticed another feature about these lunar craters that is unusual. Some of the large craters have central peaks extending up from the flat crater floor. Figure 6-1 is a view of the crater Theophilus. The central peaks (arrow) show very clearly. The crater is almost 100 km in diameter and approximately 6.5 km deep. The central peak is more than 2000 metres high. It compares with the tallest mountain in the eastern United States.

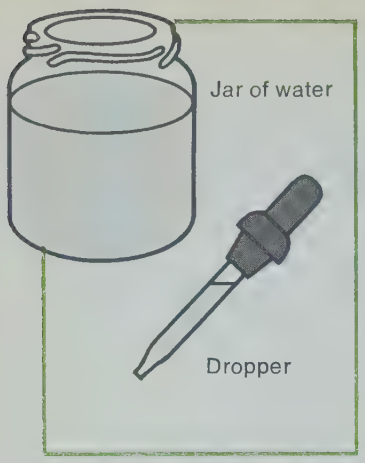


The crater Theophilus is relatively close to the landing site of Apollo 16, on April 20, 1972. It is located in the eastern part of the highlands close to Mare Nectaris, in grid F 5 on your lunar chart.

Figure 6-1

Scientists know that when a meteorite strikes a surface at high speed, a tremendous amount of heat is produced. They believe both the surface and the meteorite melt. Thus, both behave like liquids. This liquid behavior could certainly affect the appearance of the surface following the impact. To see what effect may occur, you need to examine the behavior of liquids on impact. To do this, you will need the following equipment.

1 medicine dropper
1 jar or glass of water



ACTIVITY 6-1. Fill the dropper with water. Hold it a short distance above the jar of water. Let one drop of water fall, watching the surface of the water in the jar carefully.

Repeat Activity 6-1 several times, watching the surface of the water from different viewpoints.

☐**6-1.** Describe the action of the surface of the water as the drop hits it.

Giving an accurate description was probably difficult. The action occurs very fast. High-speed photographs have been taken of a drop hitting the water's surface (Figure 6-2).

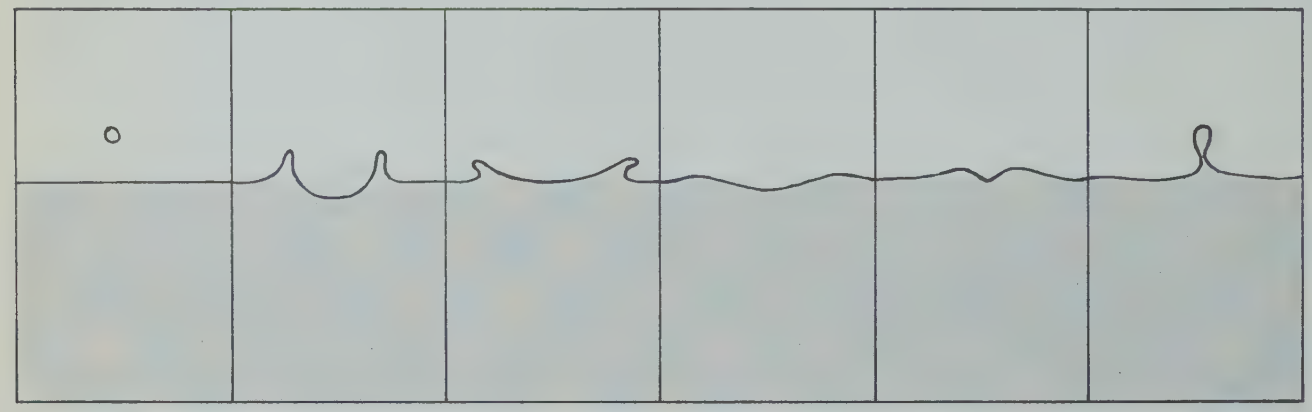


Figure 6-2

In this activity, both the impacting body (the water droplet) and the surface it hits are liquid. In the next activity, the water drop hits a solid surface with a semi-solid (powder) on it. It might be interesting to you to do a third type of modeling, with a fluid surface impacted by a solid object. If you mix up some bentonite with just the right amount of water in a paper cup (fairly thick, like heavy cream), a ball dropped into the cup will form a crater with central peak, raised rim, and sloping walls that will hold their shapes. But it is messy and quite tricky to get just the right consistency.

Here is the sequence of events.

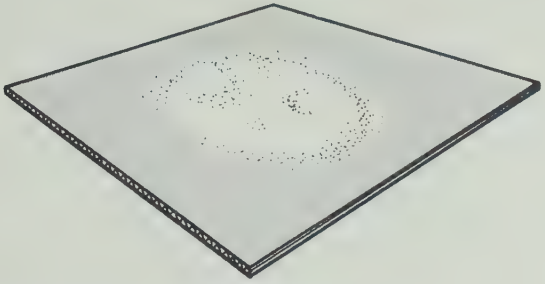
1. The drop nears the surface.
2. A crater forms as the drop hits.
3. The crater widens.
4. The crater flattens.
5. The edges of the crater flow back toward the center.
6. A central peak forms as the edges come back together.

Now find out what happens when a drop of water hits the bentonite surface that represents the moon. In addition to the medicine dropper and water, you will need the following equipment:

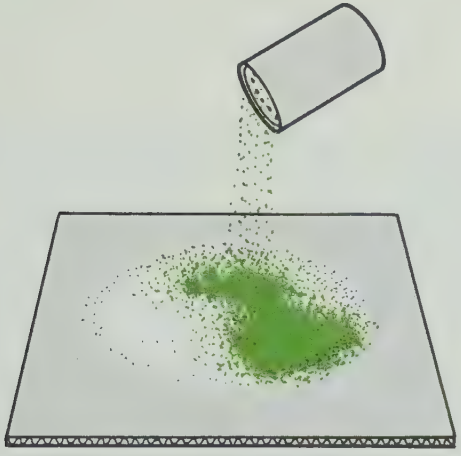
1 piece of cardboard
Bentonite
Rottenstone

ACTIVITY 6-2. Spread a layer of bentonite on the center of the cardboard. Have the layer vary in thickness from about 2 mm in one spot to just barely covering the cardboard in another.

It would probably be wise to continue to use the newspaper under the cardboard. The ejected material may splash some distance (which is what happens on the moon, and is a good point in the activity).

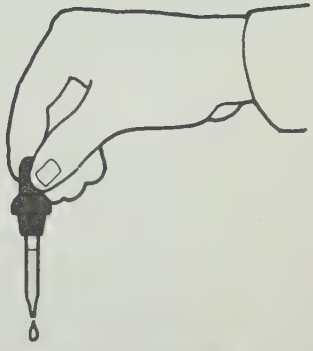


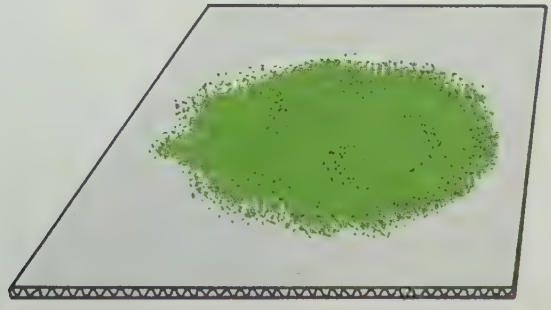
ACTIVITY 6-3. Dust a very thin layer of rottenstone over all the bentonite layer.



ACTIVITY 6-4. Drop water, one drop at a time, from the medicine dropper onto the material on the cardboard. Have one drop hit where the layer is thick. Have another hit where the layer is thin.

Try to get at least one pair of overlapping craters. Save your craters to help you answer the following questions.





If you have hand magnifiers available, you may want to let students use them to examine the small crater. If the crater formed on the cardboard is 1 cm across, and represents Theophilus, which has a diameter of 100 km, then the scale factor is 1:10 000 000. It is difficult for students to visualize this great a difference in size, and magnification might help a little. There should be central peaks (6-2), they should be most pronounced where the layer was thick (6-3), and this suggests that the material became more liquid in some places than in others because the impact was greater (6-4). It may have been broken and liquified to a greater depth.

☐**6-2.** Can you identify any central peaks in the drop craters?

☐**6-3.** If your answer to question 6-2 is Yes, did the most pronounced peaks form where the layer was thick, or thin?

☐**6-4.** Use what you learned in this activity to explain why you think some craters on the moon have central peaks and others do not.

Not all the features that stick up from the floor of craters are formed in the same way as the central peaks. For a number of years, careful scientific observers have sighted what appeared to be glowing red spots in the region of the crater Aristarchus (Figures 5-22 and 5-23). In fact, the floor of Aristarchus is surprisingly similar to that of Hawaiian volcanoes. Therefore, it is believed some kind of volcanic activity may still be in progress on the moon.

Aristarchus is located on the western edge of the Ocean of Storms (Oceanus Procellarum) in grid B 3 on the lunar chart. A hand magnifier will show what appear to be several boulder tracks caused by large rocks rolling off the domed hills. Possibly these were chunks thrown up from inside in volcanic activity. Several of the boulders are visible at the ends of the tracks.

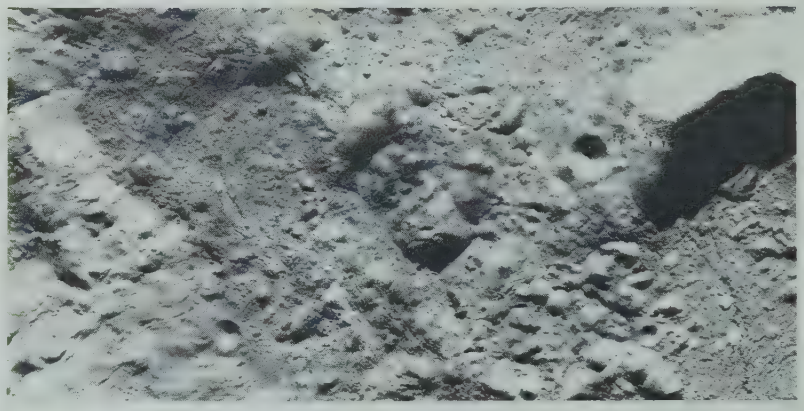


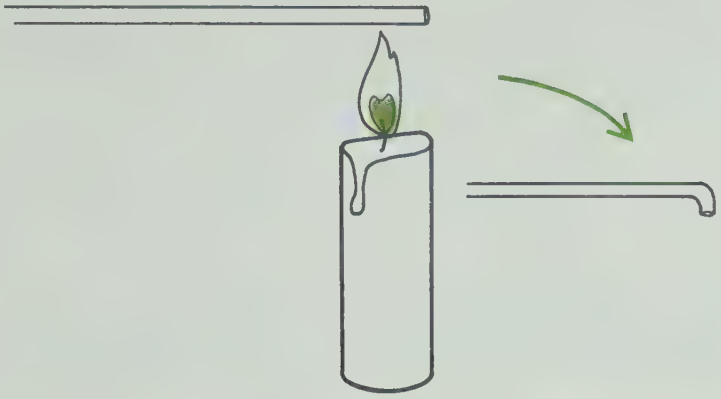
Figure 6-3

Figure 6-3 shows a closeup of Aristarchus. Note the fairly flat, ridged floor and the many dome-shaped hills.

In one type of volcano, solid material consisting of cinders, ash, and rock is thrown out of a central opening. A simple activity can show you what type of formation can be expected. You will need the following equipment:

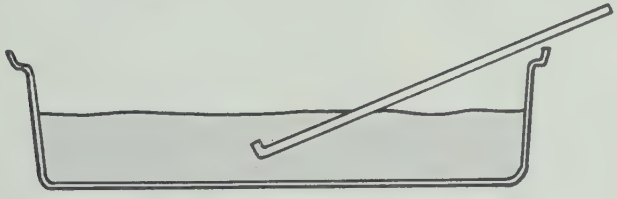
1 plastic straw
1 candle (or burner if available) and matches
1 pan of sand
1 sheet of newspaper
1 floodlight

ACTIVITY 6-5. Light the candle. Gently heat the straw about 1 cm from the end. Move it back and forth over the flame as you heat it. When it starts to bend, remove it from the flame and form a right angle bend as shown. Blow out the candle.



Emphasize the gentle heating of the straw in making the bend. Actually, very little heat is necessary, and it can be done with a match only, if care is taken.

ACTIVITY 6-6. Lay the newspaper on the table, and place the pan of sand on it. Push the bent part of the straw under the surface of the sand, with the bend pointing upward. *Gently* blow into the straw.



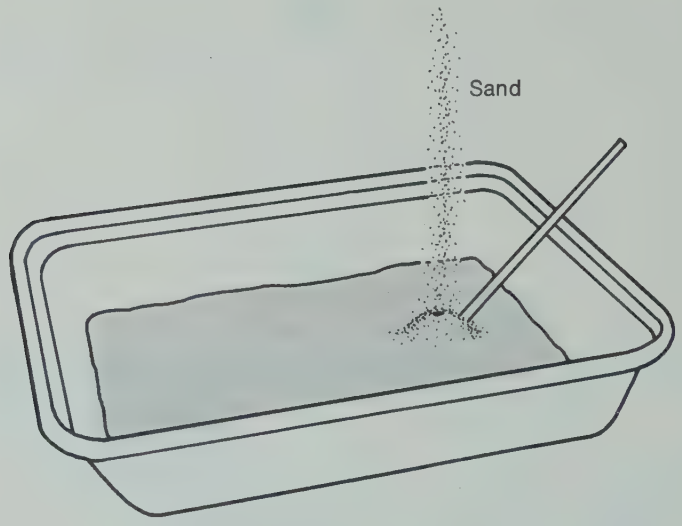
The key is gentle blowing. Not only will the sand be scattered around the room with violent blowing, but a cone will not form because the sand is pushed too rapidly out of the pan.

The crater and mound that you have just formed should look a bit like the one shown in Figure 5-9 and another you can see in Figure 6-4. However, there is one difference. When a cinder cone is formed, like that shown in Figure 6-4, a lot of material is brought up from under the surface.

Figure 6-4

The cinder cone of Parícutin (Figure 6-4), one of the few volcanoes that have formed in modern times, is in Mexico. It began to grow in a cornfield in 1943 and is now more than 400 metres high.

Using the straw, you may have found you didn't have enough material to be lifted by the air. Try doing the activity in a slightly different way.



ACTIVITY 6-7. Smooth out the sand. Blow into the straw as before, but at the same time pour sand from your hand into the crater. You will be furnishing the material from above instead of underneath. Continue blowing for a short time after you finish pouring.

☐**6-5.** How does the shape of the cone compare with the cinder cones in Figures 5-9 and 6-4?

☐**6-6.** Is the position of the crater in the mound similar?

☐**6-7.** Is the shape of the crater similar?

☐**6-8.** What is the position of the crater floor with respect to the surrounding area?

☐**6-9.** What happened to the ejected material?

Several cinder cones (X) show on the far wall of the moon crater Copernicus (Figure 6-5). There are also craters nearby (Y) that look different from those in the cones. The cone near

Students may raise the question, "How does one recognize a crater as volcanic?" Because most craters that have been suspected of being volcanic are much smaller than the large impact craters, it has been more difficult to examine them in photos. Most craters that seem to be clearly volcanic in appearance are found within large impact craters. They can be recognized by one or more of the following characteristics.

a. They appear to be roughly circular cones with a relatively small crater in the top. The area of the crater is small compared with the total area of the cone.

b. The floor of the crater is higher than the surrounding surface area.

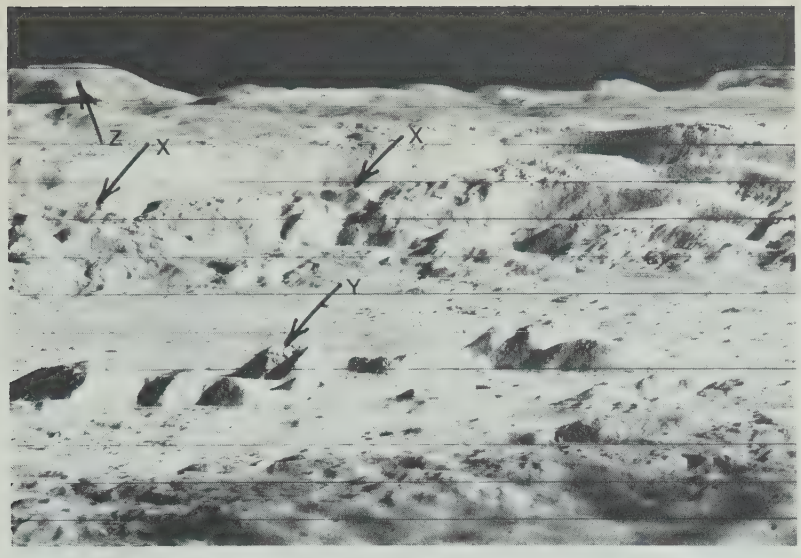
c. The outer slope of the cone is steep rather than relatively gentle as is the slope of the impact cone.

d. There may be lava flows in the area that appear to be associated with the cone.

e. There may be blocks of rock exposed in the crater walls and spilled down the slopes of the cone. These blocks are seldom blasted out to great distances as in the case of the area around impact craters.

f. In a few cases there is a dark halo around the crater believed to be volcanic. This halo is interpreted as evidence that igneous material has been blown out of the interior of the moon onto the surface.

g. Small craters believed to be volcanic occur in strings along the bottom or sides of the winding valleys known as rilles. It is thought that rilles were caused by cracking, faulting, or settling of the lunar surface, and the resulting fissures allowed volcanic activity to take place on the surface.



This picture, taken by Orbiter II in 1966, was called the "Picture of the Year." It gave the first real closeup view of the interior of the crater Copernicus. The camera was only 45.9 km above the surface of the moon. The piles of material above the center of the photo slumped off the north wall to the floor. Students have seen this effect to a much smaller scale when they let water drops hit a bentonite layer on cardboard.

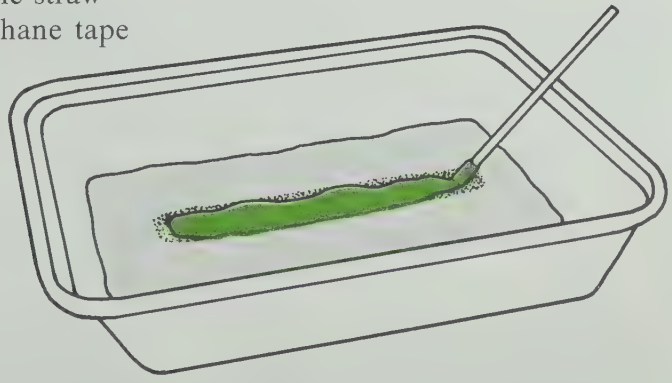
Figure 6-5

the upper left corner (Z) shows rocks inside the crater and on the outer slope of the cone. The same features show in the cone at the bottom (Y).

In some earth volcanoes, melted rock builds up pressure under the ground. It bulges the solid rock above it upward.

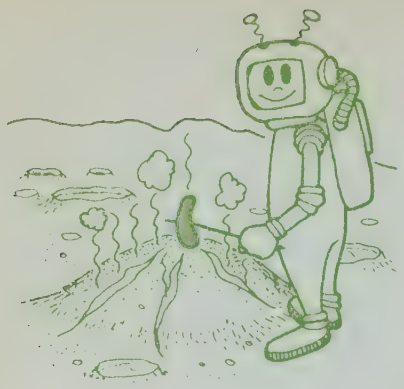
The following activity will help you visualize what happens in such a case. You will need the following equipment:

1 pan of bentonite
1 balloon
1 plastic straw
Cellophane tape



Be sure that the balloon used is the long, thin one, not the spherical-shaped one.

ACTIVITY 6-8. Fasten the balloon to the straw with tape. Dig a deep trench in the bentonite, and lay the balloon in it, with the other end of the straw over the edge of the pan. Cover the balloon with bentonite, and smooth it down. Then blow gently into the straw.



☐**6-10.** Describe the action of the bentonite as the balloon expands.

An underground flow of molten rock, called *magma,* could exert a lifting force like this on the moon's surface. This could have caused the surface to become domed and cracked. If the pressure of the magma were great enough, the fluid lava could have flowed out through the cracks, or fissures, and formed pools, or flows, on the moon's surface. Successive layers of lava could have covered the original dome that was formed, creating a domed mountain.

Domed mountains like this are found on the earth. In fact, the upwelling of molten lava is a principal feature of the shield volcano, which is common to Hawaii. The huge dormant volcano Mauna Loa is really a gigantic pile of lava, 100 km long, that has been built up in a long series of so-called "quiet" eruptions. This lava rises up through fissures in the ground, flows over the area in thick layers, and solidifies into gentle-sloping domes. Though perhaps not so spectacular as the eruptions from the classic cone-shaped volcanos, like Vesuvius, the shield domes are better understood because it is easier to get closer to study them.

Figure 6-6

Large areas of California, Oregon, and Washington are covered with lava flows from volcanic activity that occurred centuries ago. When lava cools from its over 1000 °C temperature, it forms a rocky layer rich in minerals. On the earth, this surface is changed by weathering. No weathering process takes place on the moon, but the surface becomes scarred by meteor impacts and covered with dust.

☐**6-11.** Why is there no weathering effect on the moon's surface?

6-11. Because there is no atmosphere, wind, or water. (However, there are greater temperature changes, which might be thought of as a form of weathering as the surface alternately expands and contracts.)

Notice the pattern of domes and ridges in the foreground (Figure 6-7). The crater Marius is in the upper right background. The domes (D) are up to 16 km in diameter and almost 500 metres high. They are similar to volcanic domes in northern California and Oregon. The irregular ridges (R) could have been formed by lava flowing over the surface.

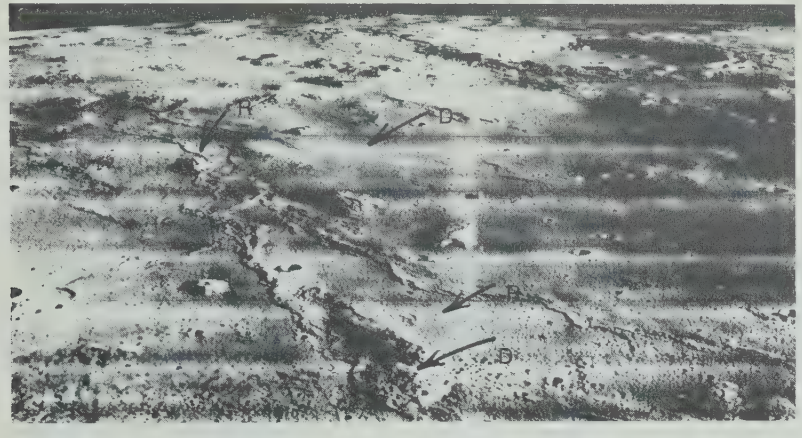
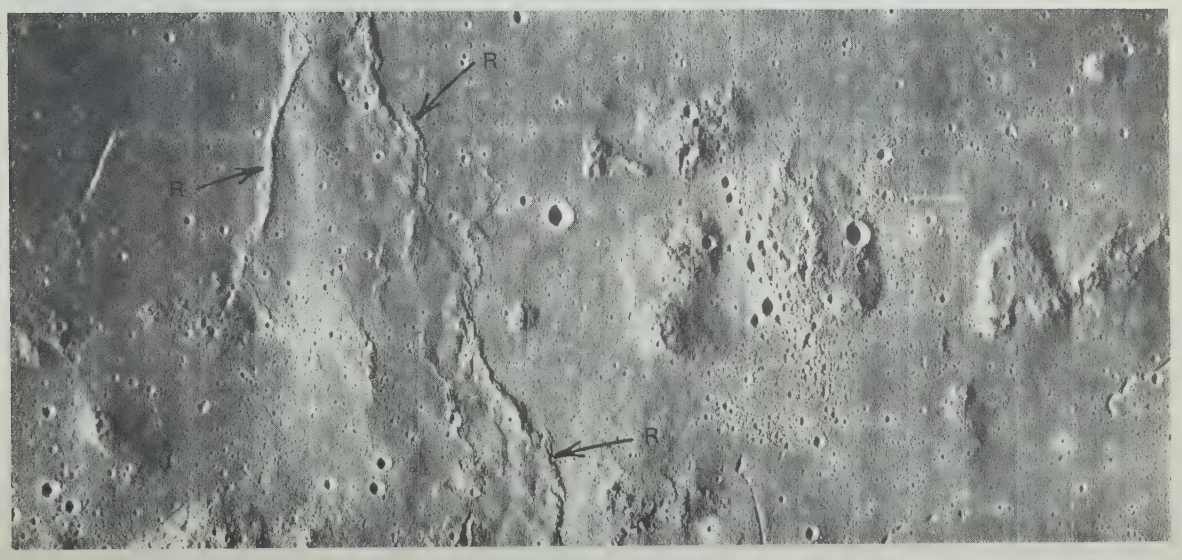


Figure 6-7

Many of the dark sea areas on the moon look quite smooth. Others, however, have domes, cones, and ridges. The seas look as if they might have resulted from lava flow.

Figure 6-8 shows the Marius Hills area of the largest mare, the Ocean of Storms. Notice the domes and cones, some of which are believed to be volcanic. Notice also the wrinkled ridges (R) running nearly continuously across the mare.

Figure 6-8



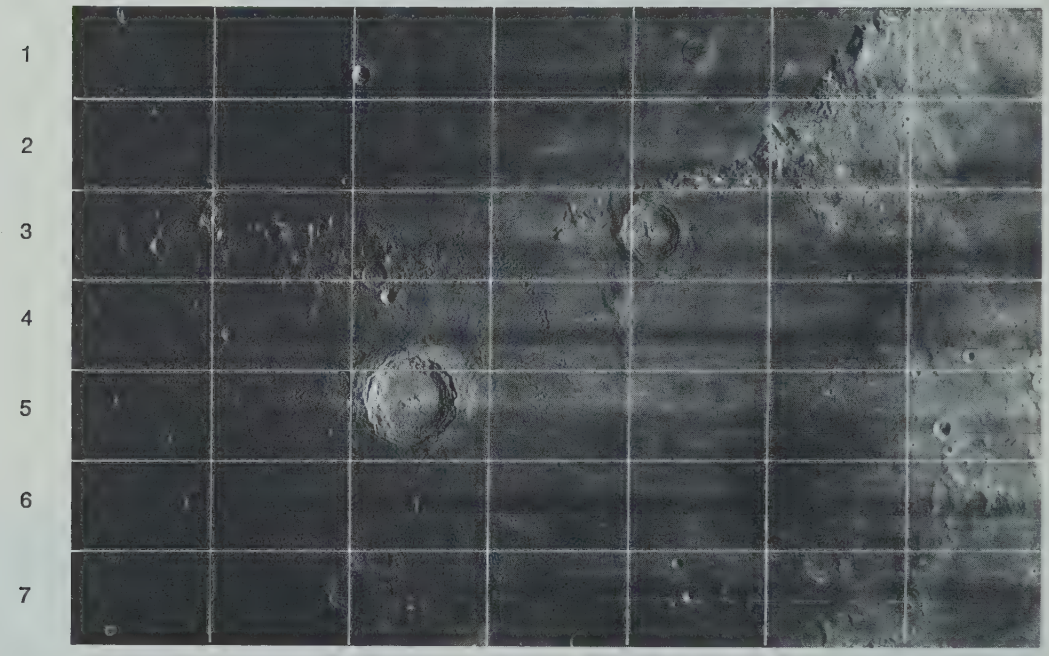
Students may need help in reading a letter and number grid like Figure 6-9. However, the problem break offers an opportunity for resourcefulness and ingenuity. It should be emphasized that there are no "right" or "wrong" answers for the oldest or youngest features. In fact, there might even be disagreement among competent lunar geologists on the listing. But there is good opportunity for small-group discussion with the students.

PROBLEM BREAK 6-1

One of the things that scientists have been most interested in is the relative age of various features on the moon. A principal reason for bringing back samples of rocks was to be able to find out how old they are. It is felt that the age of parts of the moon might tell the age of the earth and also how they both were formed.

But there are ways of telling the relative age of parts of the moon without actually going there. Figure 6-9 shows a large area containing seas, craters, rays, and mountains. A letter and number grid has been added to aid in locating the various features. Try your hand at deciding which features are oldest and which youngest.

Figure 6-9



The following list identifies the features that will be used in the dating:

1. C 5 is the brightly rayed crater Copernicus.
2. E 3 is the unrayed crater Eratosthenes.
3. D 4 to D 5 is the ghost crater Stadius.
4. E 1 is the crater Wallace.
5. E 3 to G 1 is the Apennine Mountains.
6. EF 1 to E 2 is the Sea of Rains (Mare Imbrium).
7. F 3 to F 4 is Seething Bay.

Examine the photograph carefully for clues. For instance, you will note that the bright rays from Copernicus extend across the figure in all directions. They even extend right across Eratosthenes. Some of the craters have very little dark mare material in their floors. Others are partly filled with it, like Wallace, or completely submerged, like Stadius.

The black mare material comes right up to the Apennine Mountains, like waves lapping on a seashore. Look at the moonchart in your classroom. You will see that these mountains are only part of a huge chain of mountains that continue around the Sea of Rains for almost a full circle. It looks as if an extremely large crater had been formed, with the mountains as the rim of the crater.

Make a list of the seven features above, having the oldest feature at the top of the list and the youngest feature at the bottom. If you feel that you can't tell the difference in age between two things, list them together (as the same age). Use all the available clues in making your decisions. Then write one sentence about each of your choices, telling how you decided on its place in the list.

You have investigated the appearance of some of the big features on the moon. The activities should have provided a possible explanation for the way craters, peaks, and some ridges were formed. It also may have helped you see how the relative ages of features on the moon are judged.

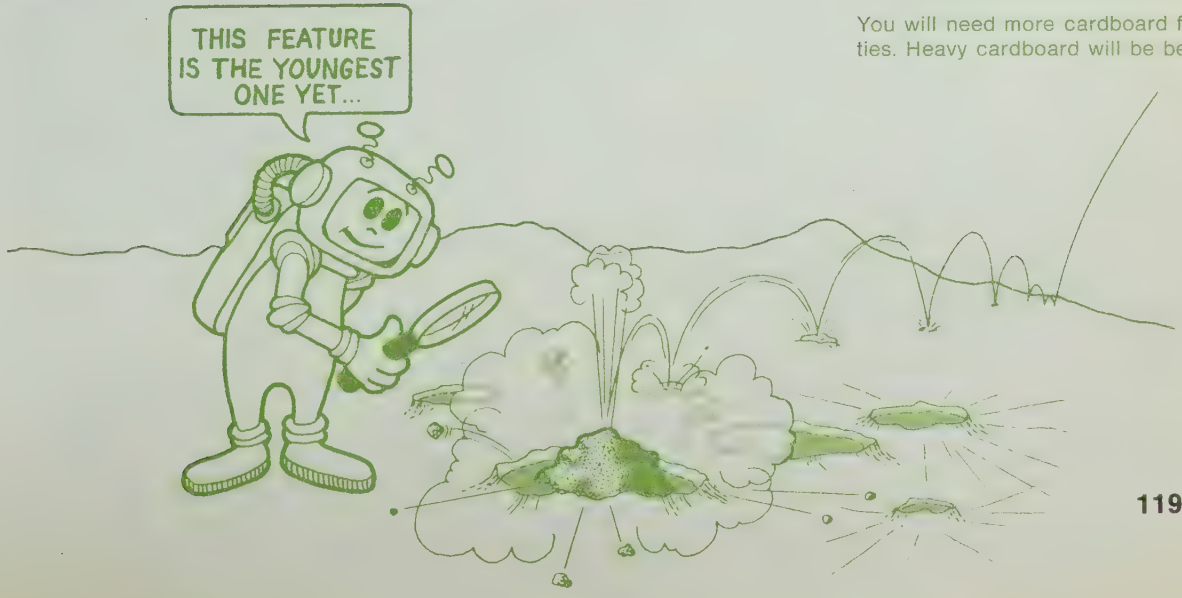
Before going on, do Self-Evaluation 6 in your Record Book.

A possible listing is as follows:
1. Apennine Mountains—These mountains are believed to be the crater rim for the huge Imbrium crater, which was probably formed relatively early in the life of the moon. The so-called Imbrian Incident, caused by the impact of a large meteor or comet, must have been a cataclysmic event. The Sea of Rains (Imbrium "crater" is about 1200 km in diameter.
2. Stadius—Because it is flooded with mare material, it occurred before the flat mare was formed.
3. Wallace—It isn't flooded as much as Stadius, and its rim is sharper.
4. Sea of Rains—The lava flowed into the entire basin after the rim was formed.
5. Seething Bay—This may have been formed at the same time as the Sea of Rains, but if the lava came from the sea, it took longer to reach the bay.
6. Eratosthenes—This large crater has sharp features, is unflooded, and must have formed after the mountains and seas because it cuts into them.
7. Copernicus—Its rays cross all the other features in the photo, so it must have been made after they were.

You can be relatively sure that Copernicus is the youngest, and that the seas were formed after the craters that they flooded. All others could be in different order. Incidentally, Apollo 15 landed at the base of the Apennine Mountains on the Sea of Rains. Mount Hadley, close to the landing site, is a little south of due east of the large crater Archimedes. That section of the Sea of Rains is called the Marsh of Decay.

GET IT READY NOW FOR CHAPTER 7

You will need more cardboard for the activities. Heavy cardboard will be best.



A Day on the Moon

CHAPTER EMPHASIS

A landing on the moon is difficult, and protection is needed for anyone on its surface. Because of the sun-earth-moon relationship, a moon day is greatly different in length from an earth day.

EQUIPMENT LIST

Per student-team

1 floodlight
1 large Styrofoam ball
1 small Styrofoam ball
2 T-pins
1 piece of cardboard

MAJOR POINTS

1. Using a physical model of the sun-earth-moon system (the bulb and two balls) the following points are developed.
   a. A lunar observer could see the whole earth in 24 hours.
   b. The same part of the lunar surface always faces the earth (the other side has been photographed via satellite).

Excursion 7-1 is keyed to this chapter.

Filmstrip Key

Enrichment
Living on the Moon

7

   c. The phases of the moon depend upon relative position of sun-earth-moon, with the most important factor being the moon's movement around the earth.
   d. To an observer on the moon, the moon's revolving about the earth produces phases of the earth.
   e.

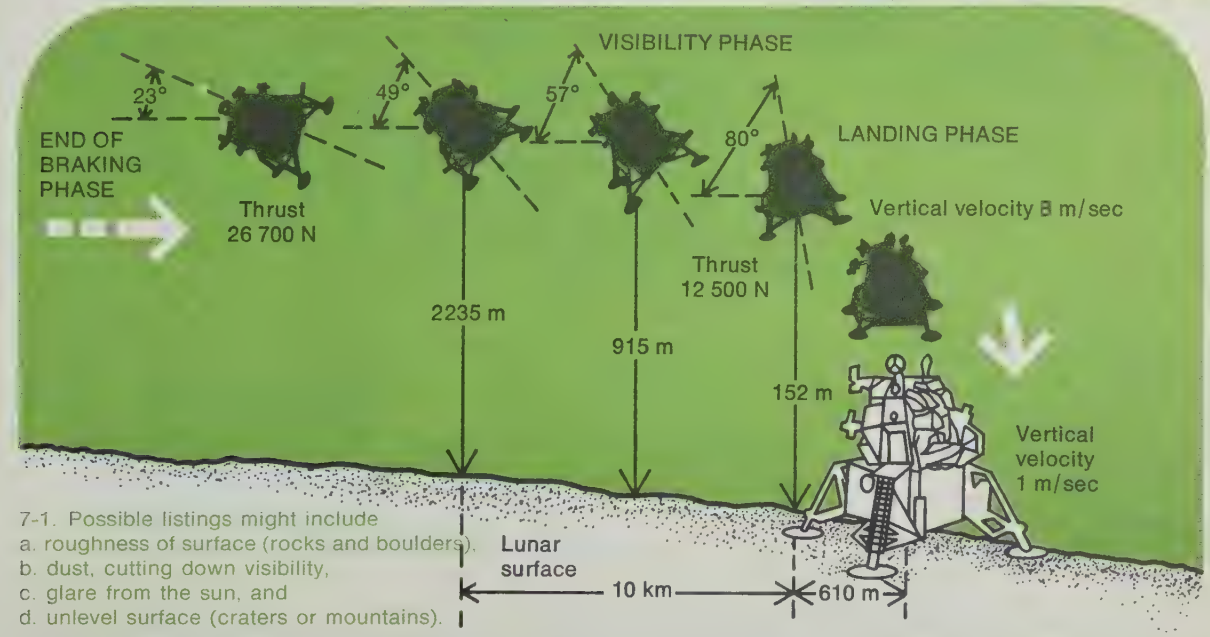
Relative position of bodies	Moon's appearance from the earth	Earth's appearance from the moon
S — M–E	1st Quarter	3rd Quarter
S — E–M	Full	New
S — E–M	3rd Quarter	1st Quarter
S — M–E	New	Full

   f. Eclipses could occur during new or full phases when bodies are in the same plane.

Your spacecraft has been orbiting the moon while you've examined its features from a distance. Now it's time to descend to the surface.

The method of getting down has been worked out. While in lunar orbit, the lunar module (LM) separates from the command module. One person remains in lunar orbit in the command module while the other two descend in the LM (Figure 7-1).

Figure 7-1



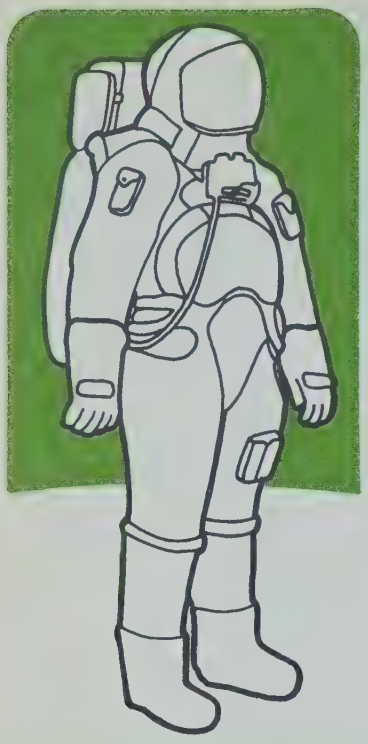
7-1. Possible listings might include
a. roughness of surface (rocks and boulders),
b. dust, cutting down visibility,
c. glare from the sun, and
d. unlevel surface (craters or mountains).

☐**7-1.** From the observations you have made, list the things you might encounter at your landing site that could make the landing difficult.

   g. Reflected earthlight (moonlight) dimly lights the new moon (new earth).

   h. Seeing only one side of the moon from the earth is due to the fact that the moon turns once on its own axis each time it makes one complete revolution around the earth.

2. The period of the moon's revolving about the earth is $29\frac{1}{2}$ days.
3. The period of the earth's revolving about the sun is $365\frac{1}{4}$ days.



7-2. You and the suit would only weigh $\frac{1}{6}$ as much on the moon. (But the suit would still be very bulky and restrictive, and the condition of the lunar surface might have an effect on walking.)

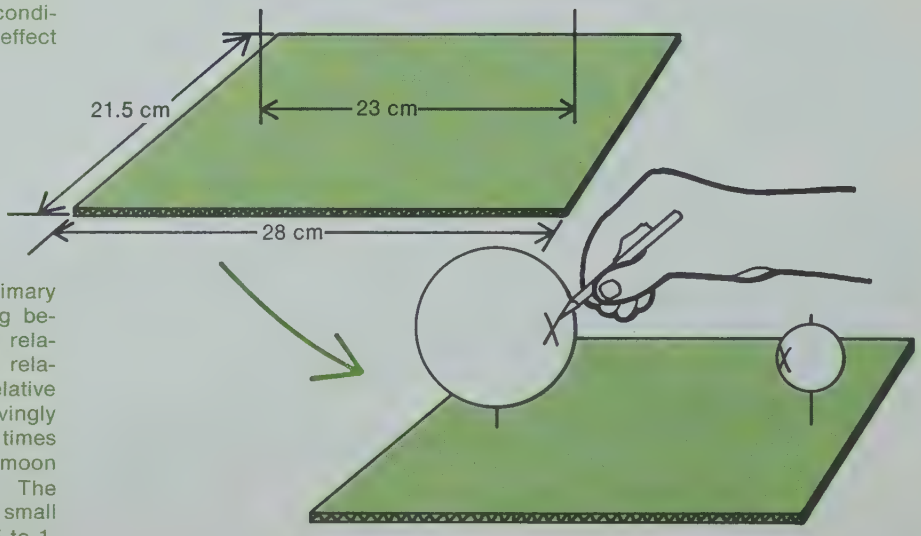
Before leaving the LM, you would put on a heavy protective suit.

☐**7-2.** With this heavy suit, it would be somewhat difficult to walk around on the earth. Why would it be easier to walk on the moon?

Suppose you stepped out onto the moon's surface just at sunrise. How many hours of sunlight would you have to investigate its surface? In other words, how long is a moon day?

For most places on the earth, daylight usually lasts only part of each 24-hour period. What is a moon day like? The following activity can show you. Work with a partner. You will need the following apparatus:

1 floodlight
1 large Styrofoam ball
1 small Styrofoam ball
2 T-pins
1 piece of cardboard



The size of the cardboard is not of primary importance, and neither is the spacing between the two balls. Only a position relationship is being modeled, not a spatial relationship to any scale. Nor are the relative sizes to exact scale, but they are deceivingly close. The diameter of the earth is 3.67 times as great as the diameter of the moon (12 760 km compared with 3480 km). The large ball is 7.5 cm in diameter and the small one 2 cm in diameter, or a ratio of 3.75 to 1. The two Styrofoam balls could be spaced 2.25 m (225 cm) apart on a bulletin board, or hung from the ceiling, to represent the earth and moon in correct spacial relationship.

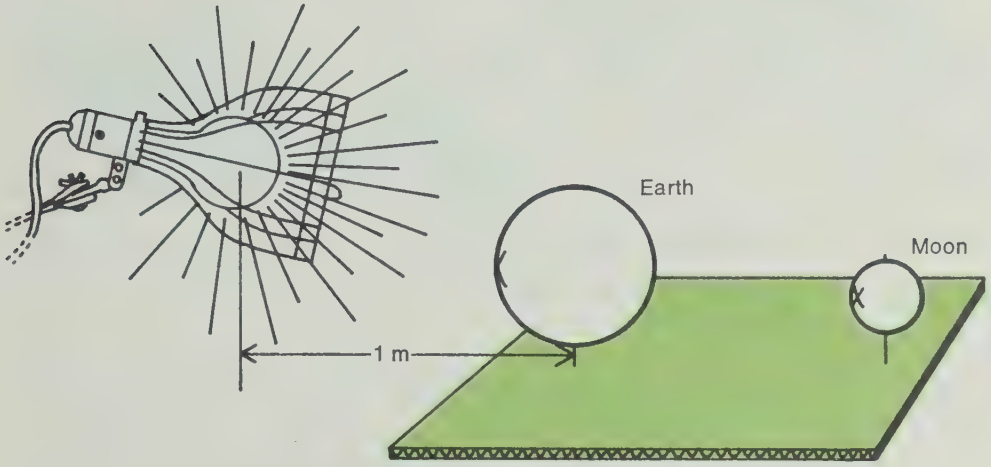
ACTIVITY 7-1. Push the two T-pins up through the cardboard at the positions shown. Push the large Styrofoam ball onto one pin, and the small ball onto the other pin. Mark an X on each of the balls with a pencil or pen.

ACTIVITY 7-2. Set up the floodlight about 1 m away on the table or floor. Turn the balls until you have the X marks in line and facing the floodlight.

The light represents the sun. The large ball represents the earth and the small one the moon.

We know that the same side of the moon always faces the earth. Therefore, the X mark on the moon must always be toward the earth.

The orbits of the earth around the sun and the moon around the earth are not in the same plane. If they were, every time the sun, earth, and moon got into the position shown in Activity 7-2 there would be an eclipse of the moon (in other words, every month). For this reason it is probably advisable not to have the three objects (light, large ball, small ball) in a perfectly straight line, but rather to have the floodlight either above or below a straight line.



When the earth rotates once, this represents a 24-hour day. On your Styrofoam earth—the large ball—the X would move in a complete circle during that period.

☐**7-3.** How much of the earth's surface could be seen from the moon in this 24-hour period?

☐**7-4.** How much of the moon's surface would an observer on the earth see during the 24-hour period?

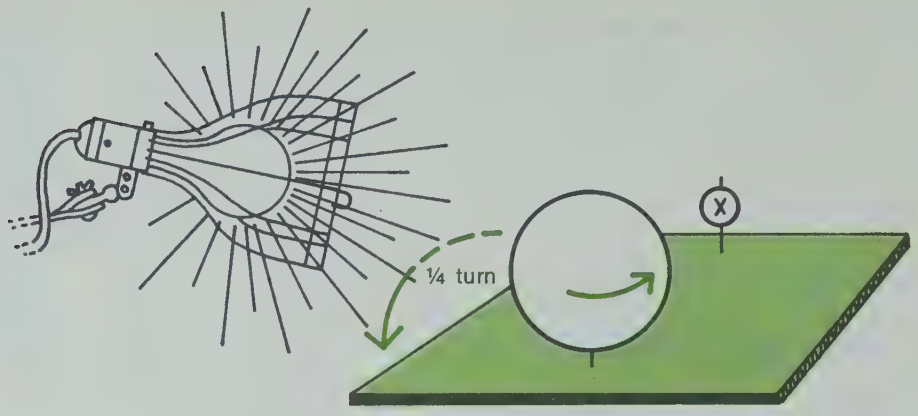
☐**7-5.** Would the side of the earth that is toward the moon in Activity 7-2 be sunlit, or dark (moonlit)?

☐**7-6.** Would an observer on the earth see a full moon, a half moon, or a new moon (unlighted)?

7-6. A full moon, unless the moon were eclipsed by the earth

The entire earth-moon system, as represented by the cardboard and balls, rotates once in relation to the sun every $29\frac{1}{2}$ days. So in a little over a week (seven earth days), the system would make a quarter turn.

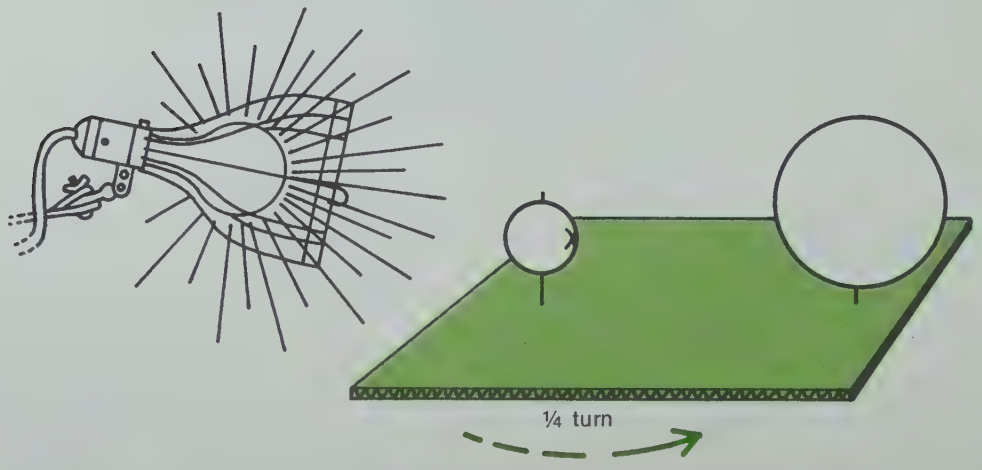
ACTIVITY 7-3. Turn the cardboard counter-clockwise as shown. Remember the X on the moon must always point toward the earth.



The floodlight (sun) is now shining across the cardboard. The earth has rotated on its own axis (pin) a little more than seven times.

☐**7-7.** As seen from the Styrofoam earth, how much of the moon is lighted?

☐**7-8.** As seen from a man at X on the moon, how much of the earth is lighted?



When the Lunar Orbiters photographed the far side of the moon, the three bodies were in this relative position for some of the pictures.

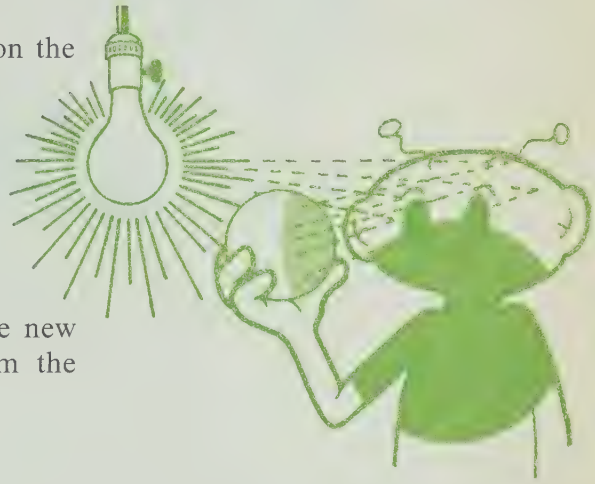
ACTIVITY 7-4. In just over seven days more, the earth-moon system rotates another quarter turn. Rotate the cardboard as shown. The moon is now closer to the sun, with the X still toward the earth.

☐**7-9.** As seen from the earth, how much of the moon is now lighted?

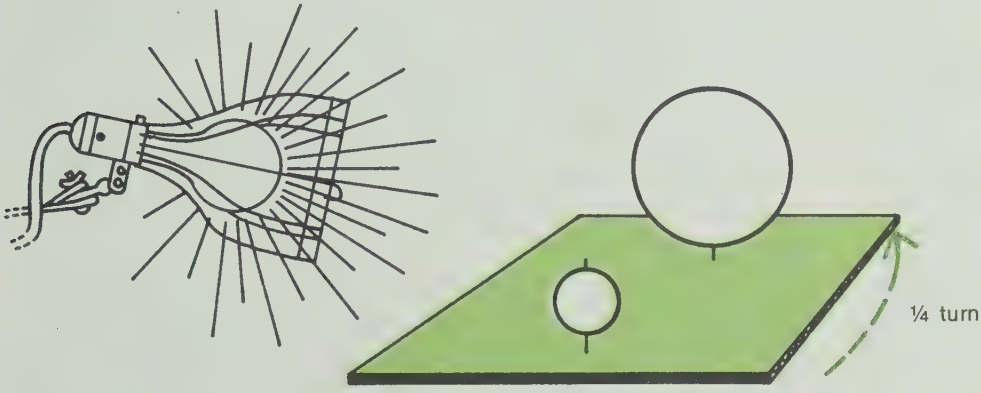
7-9. None. The new moon is mainly illuminated by earth light (7-10), which is the light from a "full" earth as seen from the moon. A small amount of illumination is due to starlight, which would be somewhat brighter than on the earth because of lack of atmospheric interference.

The moon in Activity 7-4 is called a *new* moon. Actually it is not completely dark on the side toward the earth. An observer can make out some of the larger features.

☐**7-10.** Where does the light come from that shines on the face of the moon, making it slightly visible?



If it weren't for this source of light, the face of the new moon would be completely black and invisible from the earth.



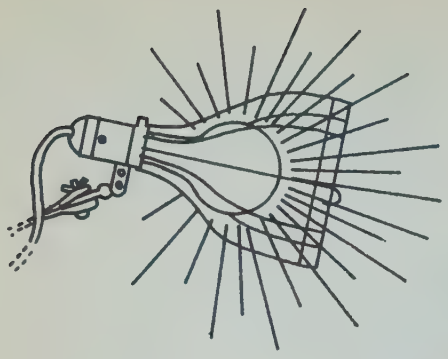
ACTIVITY 7-5. Rotate the earth-moon system another quarter turn. The X on the moon is still toward the earth.

☐**7-11.** As seen from the earth, how much of the moon is lighted?

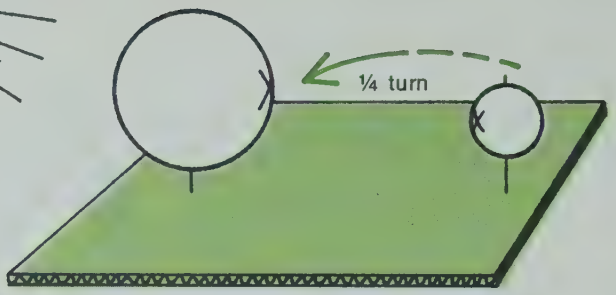
7-11. Half

☐**7-12.** As seen from the moon, how much of the earth is lighted?

This condition represents the moon at the time of an Apollo landing. The line of sunrise has just swept by the landing site in the center of the moon. There will be a long period of lunar daylight. But the temperatures have not yet climbed to where they will be at lunar noon.



ACTIVITY 7-6. Rotate another quarter turn back to the original position.



The complete circuit has taken $29\frac{1}{2}$ earth days. In other words, the earth has revolved $29\frac{1}{2}$ times with respect to the sun, while the whole system turned once around. The X on the moon still faces the earth.

☐**7-13.** How many times did the moon rotate with respect to the sun during the $29\frac{1}{2}$ day period?

7-13. Once (Actually, the moon didn't rotate on its pin axis at all. Because the earth and moon were in a coupled system, fastened to the cardboard, the rotation of the cardboard subsystem automatically rotated the moon once with respect to the sun. This is as it should be. Because of the strong gravitational pull between the earth and the moon, the rotational period of the moon is equal to the revolutional period of the moon around the earth. In other words, the moon rotates on its axis at the same speed—once every $29\frac{1}{2}$ days—as it revolves around the earth. This results in a moon day with a length of $29\frac{1}{2}$ earth days of 24 hours each.)

Rotation of the moon with respect to the sun would be counted by the number of times in a given period the X faced the sun. Remember that you started and ended with the X facing the sun.

Here is one other thing to set the record straight. While the earth-moon system is turning, it also makes one complete trip around the sun each $365\frac{1}{4}$ days. Figure 7-2 illustrates this.

You can duplicate this picture with your model system by moving the cardboard earth-moon system around the floodlight sun. The floodlight would have to turn to face the rotating bodies at all times. Check the following list of motions to be sure that you can visualize all of them.

1. The earth-moon system revolves around the sun once every $365\frac{1}{4}$ earth days.
2. The moon revolves around the earth once every $29\frac{1}{2}$ earth days.
3. The earth rotates on its axis once every earth day (24 hours).
4. The moon rotates on its axis once every $29\frac{1}{2}$ earth days.

☐**7-14.** How long is a moon day from one sunrise until the next?

You can probably see now why everything was stated in earth days. A moon day is an entirely different thing. You can also see that if you land on the moon at sunrise, you will have ample daylight to make observations.

With the same side of the moon pointed toward the earth at all times, an earth-based observer never sees the other side of the moon. But in orbit around the moon, there is an opportunity to see and photograph the other side in full sunlight. This has been done.

Perhaps you would like to take a side trip now. If so, do **Excursion 7-1,** "An Excursion to the Far Side."

EXCURSION

Excursion 7-1 is an extension excursion that requires no equipment.

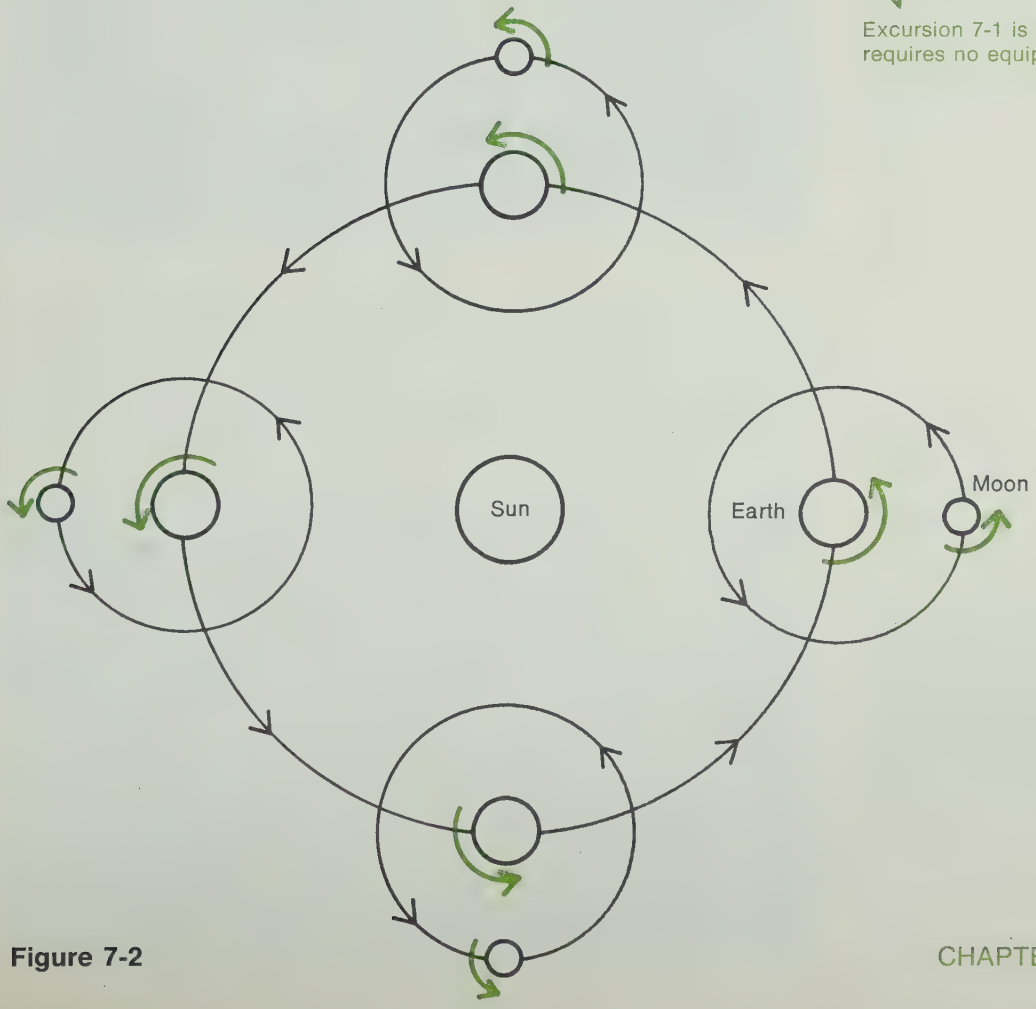
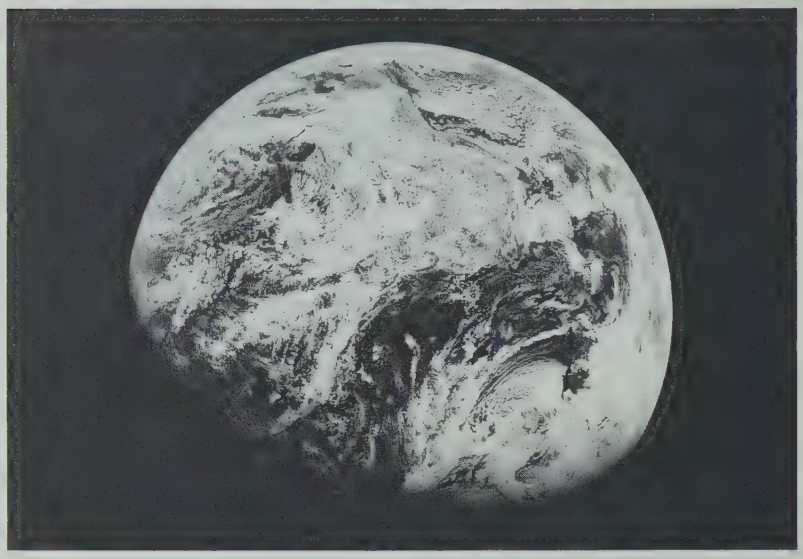


Figure 7-2

Well, your time on the moon is up. You must blast off at the right moment to meet the command module that has been orbiting. After joining up, you discard your moon vehicle and head back for the earth. There it is!

Before going on, do Self-Evaluation 7 in your Record Book.



The view of the earth shown in the accompanying illustration could lead to an additional activity or small-group discussion. In order to see the earth as it is shown, what must be the relative positions of the sun, earth, and moon? Assuming that the spacecraft is between the moon and the earth, how much of the moon would appear illuminated to the astronauts? As seen from the earth, is it a "waxing" moon—that is, becoming fuller, going toward full moon—or is it a "waning" moon—becoming less full, going toward new moon?

You may want to extend the study of space travel or lunar exploration with some of your more interested students by using supplementary sources. Your library has a number of books on the subject. There are a great many booklets and pamphlets on the various Apollo missions available from NASA and the Government Printing Office. Future projects, such as the space shuttle, can provide a good opportunity for study and small-group discussion.

Excursion 7-1

An Excursion to the Far Side

EQUIPMENT

None

This is an extension excursion.

PURPOSE

To afford the opportunity of examining some of the features on the far side of the moon.

MAJOR POINTS

1. Viewing the far side of the moon requires a trip around the moon.
2. Photographs of the far side indicate that the same kinds of events have occurred over the entire surface of the moon.

On August 23, 1966, the first Lunar Orbiter provided a view of the far side of the moon and at the same time showed the crescent earth. Figure 1 shows this first detailed scene.

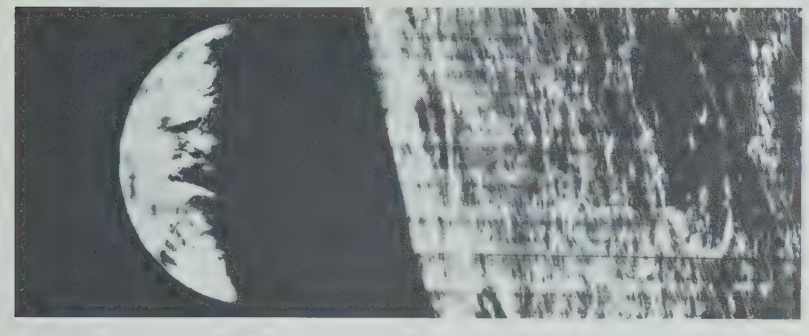


Figure 1

Note the roughness and the large number of craters. The spacecraft was almost 1200 km above the surface of the moon when this photograph was made. The Western Hemisphere of the earth is in sunlight.

Now let's suppose you, too, are making this trip. As your spacecraft swings around to the moon's other side, you see some features never observed from the earth.

☐ **1.** Why have they not been observed?

From a window in your spacecraft, you can examine some of these rare sights.

Notice the large crater near the bottom (Figure 2). Radiating from it are two deep troughs. This crater has never been named. Perhaps you would like to name it yourself. Another

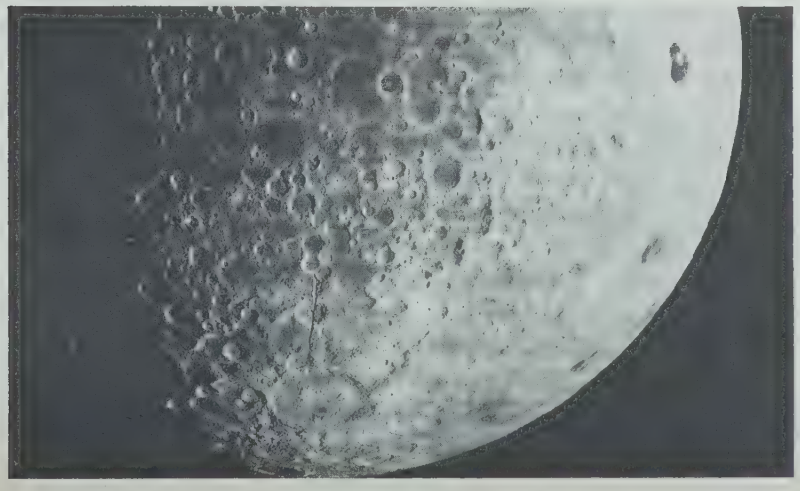


Figure 2

Figure 3

Konstantin E. Tsiolkovsky (sometimes spelled Ziolkowsky) lived from 1887 to 1935. In his writings he was one of the first to propose liquid propellants for rockets. Russia bases its claim to pioneering in rocketry mainly on his work.

feature that stands out is the dark area with a light spot in it, in the upper right corner. This is the crater Tsiolkovsky. Let's move in and take a closer look at the troughs and the unnamed crater (Figure 3).

The one trough extends northward for more than 250 km. In some places it is as much as 8 km wide. The edges are sharp. Notice how the trough cuts right across several craters.

☐**2.** How does the age of the trough compare with the age of similar features on the front side of the moon?

2. The trough is probably quite young. It is more recent than the craters through which it cuts, and the sharp edges have not been softened by meteor impact. You might guess that it was caused by a glancing blow of a large body traveling at a high rate of speed. One small crater midway in the trough seems to be newer, however.

Now you have an even closer look at the huge crater (Figure 4). The southern third of the trough, 1, can be seen entering at the left, about a centimeter below the horizon. The trough ends at the outer rim of the crater. On the right, on the crater floor, is an elongated crater with very dark material, 2, around it.

☐**3.** What do you think could be the source of the dark material around the elongated crater?

Figure 4

Scientists view this darkened area as another possible example of volcanic activity on the moon. Once again, the pattern still seems to be that most suspected volcanism occurs on the floor of the large impact craters, as was pointed out in Chapter 6.

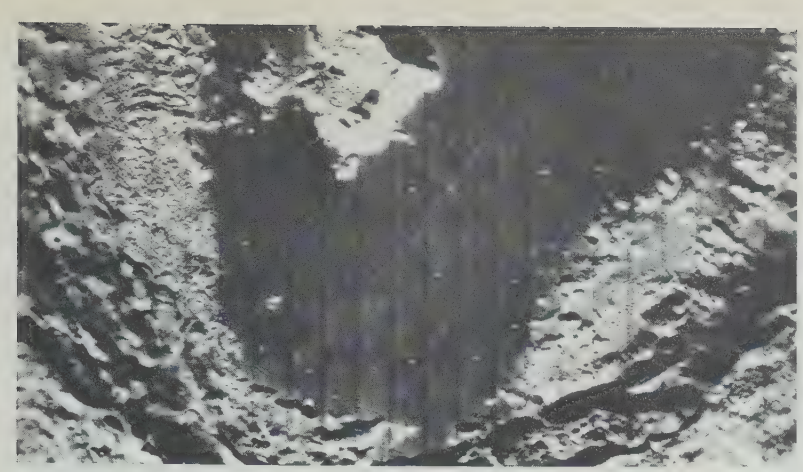


Figure 5

Tsiolkovsky seems to be a relatively young formation. The sharpness of the rim and the fresh look of the ejecta, with relatively few craters in it, support this assumption. And the dark floor material, so smooth and free of large craters, indicates that since its formation, whenever that was, there has been little impact activity (question 4), and suggests that the floor was laid down fairly recently.

Here's another view of the crater Tsiolkovsky. It is about 200 km in diameter, with a very dark, smooth floor and a prominent central peak (Figure 5).

Crater Tsiolkovsky was first viewed on the Russian Luna III photographs. The dark floor has no large craters in it. The crater rim is rough and sharp. The area around the crater shows patterns of material that was thrown out.

☐**4.** What does the lack of large craters in the dark floor suggest?

As you continue your orbit on the far side, you pass over a basin that is about 300 km in diameter. It has a faint inner ring of low hills. There are many craters in the floor (Figure 6). As you look at the photographs imagine that you are hovering above the moon.

Figure 6

5. The basin appears very old. The impact that caused the formation must have been a large one; the double ring seems to indicate that material was splashed widely and didn't come back to the center to form central peaks. Some of the smaller craters do have central peaks, however, and were all formed after the basin.

☐**5.** What do the many small craters in the floor of the large crater in Figure 6 tell you about the relative age of the basin?

Now you will get one last look north at a large section of the lunar surface (Figure 7).

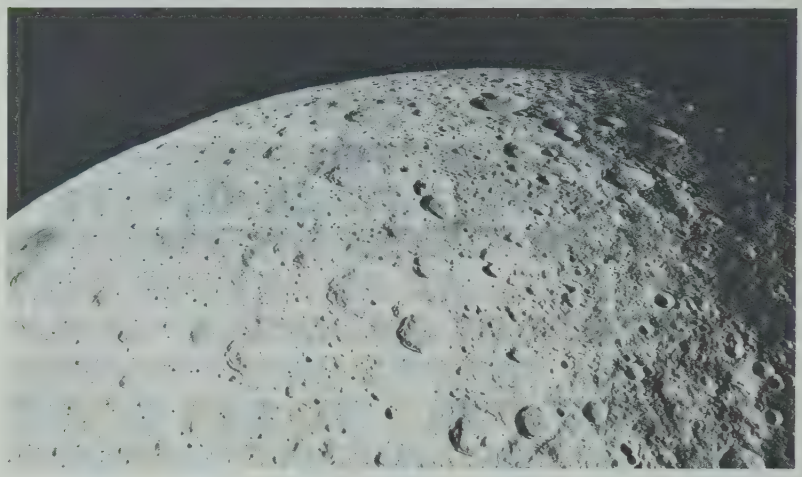
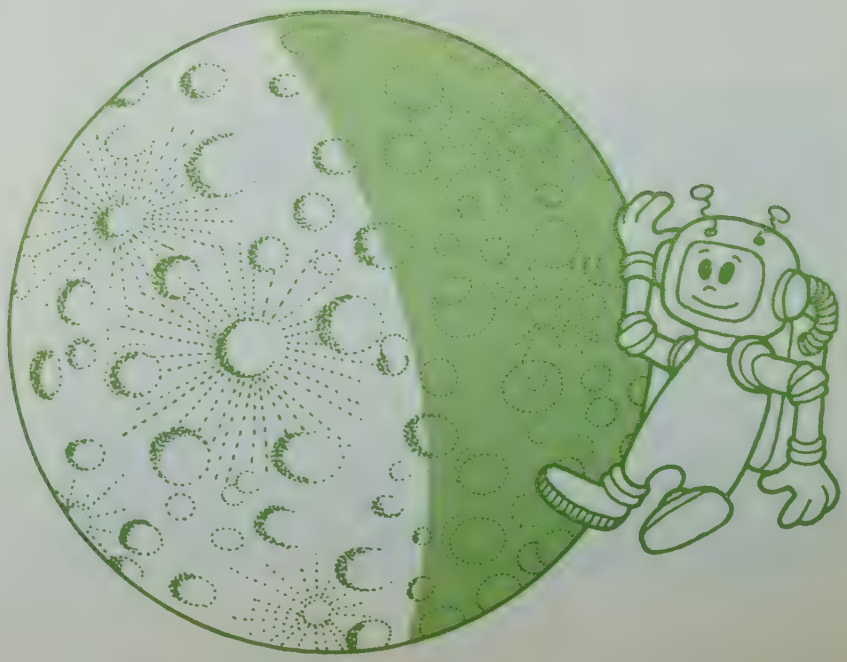


Figure 7

Well, it's time to get back to the moon's near side. You may have found your trip interesting, but the side of the moon never seen from the earth certainly offered no startling surprises. It is much like the near side—perhaps a bit more rugged, with fewer large "seas." The same kinds of features suggest that the same kinds of events have occurred over the entire surface of the moon.

The lack of large seas, or maria, has been interpreted by some students of lunar geology as meaning that the far side has not had the tremendous upwelling of magma that occurred on the near side. Some have conjectured that the earth's gravitational attraction may have played a part in this.



Index

Ablation, 69, 79–80
Age of surface areas of the moon, 118–119
Air drag, 59–60
  on the moon, 104, 106
  during rocket reentry into atmosphere, 68–69, 79–81
Air pressure, 13–15
  effect of, on rocket launching, 8–9, 21, 38
Apennine Mountains, 118–119
Apogee, 66
Apollo spacecraft, 42–43, 49
  heat shield of, 81
Aristarchus crater, 100–101, 104, 112
Aristotle, 70
Atmosphere
  moon's lack of, 98, 102–103, 106
  near the earth's surface, 60
  and rocket reentry heat, 68–69, 79–81
Atomic-blast craters, 90, 96
Atoms, 41
Attraction, force of, 74–75
Averaging, 8

Balanced force, 13, 23
  Newton's laws on, 27
Boiling, 79

California lava flows, 116
Carbon, 41
Carbon dioxide (CO_2), 41
Chamber, rocket combustion, 39–40
  fuel burning in, 41
Chemical reactions, 41
Cinder cone of volcanoes, 112–115
Coasting path, 65–66
Combustion chamber of a rocket, 39–40
  fuel burning in, 41
Command module, 43, 121
Communications satellites, 76–78
Compounds, 41
Copernicus crater, 100, 104
  age of 118–119
  cinder cones of, 114–115
Crater Lake (Oregon), 90
Craters of the earth, 88–91
Craters of the moon, 83–99, 100–101
  on the far side, 129–132

Dark side of the moon, 129–132
Dating surface areas of the moon, 118–119
Distance, and force of gravity, 106
Domed mountains, 116–117
Dust dunes of the moon, 105

Elements, 41
Elliptical orbits, 66
Energy, 40
  affected by mass and speed, 93
Energy changes, 41
  heat loss and, 79–81
Eratosthenes crater, 118–119
Erosion of crater rims, 98
Evaporation, 79
Exhaust gases of a rocket, 42
Expansion, heat, 42

Falling bodies, 56
  experiments concerned with, 70–73
  horizontal speed, mass, and, 59
Far side of the moon, 129–132
Fluorine, 42
Force
  of attraction, 74–75
  balanced and unbalanced, 13, 22–24
  laws of, 27
  lift, 18
  measured by amount of water per second from jet tube, 20
  newton units of, 26
  and Newton's third law of motion, 43, 47–49
  to overcome for rocket launching, 30–31
  push and pull as, 11
  affected by quantity and speed of water, 21
  relationship of mass, speed, and, 35–39
  speed affected by time application of, 39

Free-return path, 67–68
Friction, 60, 79
  on the moon, 106
Fuel, rocket, 39
  hydrocarbon-compound, 41

Galileo Galilei, 56, 83–84
  pendulum experiments of, 70–73
Gases, rocket exhaust, 42
Gravity, 23–24, 53, 59–60
  force of, on an empty rocket, 30
  horizontal force and, 55, 59
  of the moon, 104
  reasoning behind Newton's discoveries about, 73–75
  and weight of an object, 60–63, 106

Heat energy, 40
  during rocket reentry, 58–59, 79–81
  produced by meteor impact, 109
  released in burning rocket fuel, 41
Heat loss, 79–81
Height
  and gravitational pull, 60–64
  of a stationary satellite, 77
  water pressure and, 21
Horizontal push, 51
  gravity and, 55, 59
Hydrocarbon-compound rocket fuels, 41
Hydrogen, 41–42

Impact craters, 91, 96
Iron, 107

Kepler, Johannes, 74
Kepler crater, 100, 104
Kerosine, 41
  as rocket fuel, 42

Landing on the moon, 121–122
Lassen Volcanic National Park, 88
Lava flows, 88–89, 116
Laws of force and motion, 27, 43, 47
Lift force, 18, 20
  lift speed and, 32
  pressure and, 20–21
Liquids, behavior of, on impact, 109
Lunar module, 43, 121

Magma, 116
Mare, 83–84
Marius crater, 117
Marius Hills, 117
Mass, 30
  change in rocket, 32
  effect of, on crater formation, 93–95
  and force of attraction, 74–75
  and force of gravity, 56, 59, 106
  and Newton's third law of motion, 47–49
  relationship of speed, force, and, 35–39, 93
Matter, 40
  heat effects on, 42
Measurements of force, 11
  balanced and unbalanced, 13
Melting, 79
Meteor Crater (Arizona), 88, 91
Meteors, 95, 104, 106
Molecules, 41
Moon
  determining length of daylight on, 122–127
  far side of, 129–132
  free-return path to, 67–68
  gravity of, 106
  landing on, 121–122
  Newton's gravitational reasoning applied to orbit of, 73–75
  orbiting speed of, 59
  period of, 65
  surface of, 83–87, 98, 100–105, 109
Motion
  Kepler's laws of, 74
  laws of force and, 27
  Newton's third law of, 43, 47
  of an object above the earth's surface, 59–60
  rocket lift and, 31
Motion change, unbalanced force and, 24, 27

New moon, 125
Newton (N), 26, 47
Newton, Sir Isaac, 26, 27, 59
  reasoning behind gravitational laws of, 73–75
  and third law of motion, 43, 47
Nozzle, rocket-engine, 39, 40, 42

Ocean of Storms, 117
Operational definitions, 24
Orbit injection, 65–66
Orbit path, 65–66
  of the moon, 73–75
Orbiting and orbiting speed, 63–69
  five steps of, 65–66
  of the moon, 59
  at the surface of the earth, 56–59
  thrust necessary to establish, 51–55
Oregon lava flows, 116
Oxygen, 41–42

Parícutin volcano (Mexico), 114
Parking orbit, 59, 67
  of communications satellites, 76–78
Payload, 49
Peaks in moon craters, 109, 112
  liquid behavior and, 110

Pendulum, 70–73
Perigee, 66
Period of a satellite, 64
  communications satellites and, 76–78
Phenolic epoxy resins, 81
Potential energy, 40
Propulsion principle and burning of fuel, 42
Pull, force and, 11
Push
  of escaping gas, 22–23
  force and, 11, 21
  sidewise (horizontal), 51

Quadrant, 5
Quantity of water per second, effect of, on force, 21

Radiation of the moon's surface, 102–104
Radio signals, 76
Radius of the earth, 63, 75
Rays of the moon, 84, 119
  study of, 101–105
Reaction principle, 27
Reentry, rocket, 68–69, 79–81
Rims of craters, 98
Rocket launching, affected by air and water variables, 1, 8–9
Rotation of the moon, 126

Safety Note on rockets, 2, 9
Satellites, communications, 76–78
Saturn-Apollo rocket, 11
  fuel of, 39, 43
Sea of Rains, 118–119
Seething Bay, 118–119
Service module, 43
Shape change, unbalanced force and, 24
Space travel, 63–69
Speed
  affected by time application of unbalanced force, 39
  effect of, on crater formation, 93–95
  necessary to escape the earth's atmosphere, 66–67
  and Newton's third law of motion, 47–49
  relationship of force, mass, and, 35–39, 93
Speed of water
  effect of, on force, 21, 38
  mass and, 33–35
Squaring a number, 75
Stadius crater, 118–119
Stages, rocket, 1, 39, 43
  theory behind use of, 47–49
Sunshine, effects of, on moon's surface, 102–104
Synchronous, 77
Syncom 3 satellite, 77

Television signals, 76
Temperature, 42
Theophilus crater, 109
Third law of motion, 43
Thrust, 29
  speed of water and, 38
  weight force and, 63–64
Tilt start, 65–66
Time of force application, effect of, on rocket speed, 39
Tsiolkovsky crater, 130–131

Unbalanced force, 13
  effects of, 23–24
  motion change and, 24–25
  Newton's laws on, 27
  rocket air pressure and, 14–15
  rocket motion and, 31–32
  shape change and, 24–25
  speed, mass, and, 35–39

Variables affecting rocket launchings, 8–9
Vertical rise, 65–66
Volcanoes, 88, 112
  cinder cones of, 112–115
  craters of, 89, 91, 105
  domed, 115–117

Wallace crater, 118–119
Washington lava flows, 116
Water (H_2O), 41
Water pressure
  affected by height, 21
  affected by size of jet tube hole, 18–19
  effect of, on rocket launching, 8–9, 14–15, 38
Weathering effects on the moon, 98, 102–103, 106, 116–117
Weight
  affected by distance from the earth's surface, 60–63
  rocket lift and, 30–31, 63–64
Wizard Island (Crater Lake), 90
Wolf Meteorite Crater (Australia), 89
Work, 40

EQUIPMENT

Aluminum pans, 92, 102
  in studying moon craters, 92–99
  in studying moon rays, 102–103
Angle bracket, used with force measurer, 11–12

Baby-food jar, used with rocket test stand, 15
Ball holder, in calculating horizontal speed, 51–56
Balloon, 11, 115
  in studying volcanic bulges, 115–116
  used with force measurer, 11–12

Bar magnet, in lunar-gravity study, 106–107
Beaker, 100 ml calibrated, 1, 15, 29
in force of gravity study, 29–30
in rocket-launching study, 1, 6
used with rocket test stand, 15
Beaker of water, in lunar-gravity study, 106–107
Bentonite powder, 102, 110, 115
in liquid-impact study, 110–112
in studying moon rays, 102–103
in studying volcanic bulges, 115–116
Bucket, 5-litre, in rocket-launching study, 1, 6

Candle, 112
heat loss experiment with, 80–81
in volcanic cinder cones study, 112–113
Cardboard, 4, 110, 122
in construction of height measurer, 4–5
in determining length of moon day, 122–127
in liquid-impact study, 110–112
Cart, with water clock, 32
in studying change in rocket mass, 32–35
in studying relationship of force, mass, and speed, 35–39
Cart, without water clock, in studying Newton's third law of motion, 43–49
Cellophane tape, in studying volcanic bulges, 115–116
Clamp, used with force measurer, 11–12
Clay, in studying Newton's third law of motion, 43–46

Dry water rocket, in force of gravity study, 29–30

Floodlight, 92, 112, 122
in determining length of moon day, 122–127
in studying moon craters, 92–99
in volcanic cinder cones study, 112
Force measurer, 11, 15, 25, 29, 35, 43, 51
in calculating horizontal speed, 51–56
in construction of rocket test stand, 16
in measuring rocket mass, 30
in measuring shape change, 25–27
in measuring water pressure, 17–18
in rocket thrust study, 29, 31
in studying Newton's third law of motion, 43–47
in studying relationship of mass, force, and speed, 35–39
use of, 11–12
Force-measurer pin, in calculating horizontal speed, 51–56
Funnel, filler, with plastic water rocket, 1–2
Funnel, in force of gravity study, 29–30

Glass of water, in liquid-impact study, 109–110

Height measurer for rocket launch (Quadrant)
construction of, 4–5
use of, 6–7

Jar of water, in studying change in rocket mass, 32

Kilogram masses, in studying relationship of force, speed, and mass, 35–39

Light-sensitive paper, in solar-radiation study, 103

Magnifier, in lunar-gravity study, 106–107
Marble, glass, 70, 92
in operation of a pendulum, 70–73
in studying falling bodies, 56
in studying moon craters, 92–99
Masking tape, in rocket test stand, 15–18
Matches, in studying Newton's third law of motion, 45–46
Medicine dropper, in liquid-impact study, 109–111
Metrestick, 1, 6, 32, 51, 92, 102
in calculating horizontal speed, 51–56
in rocket-launching study, 1, 6
in studying change in rocket mass, 32–35
in studying moon craters, 92–99
in studying moon rays, 102–103
Microscope slide, in lunar-gravity study, 106–107

Newspaper, 92, 102, 112
in studying moon craters, 92–99
in studying moon rays, 102–103
in volcanic cinder cones study, 112–113
Newton scale, 11, 25
on a force measurer, 11–12
in force of gravity study, 29–31
in measuring shape change, 25–27
and rocket test stand, 18

Opaque objects (coin, key, etc.), in solar-radiation study, 103

Pail of water, in force of gravity study, 29
Pan of sand, in volcanic cinder cones study, 112–114
Paper clips, in heat-loss experiment, 80
Paper-clip hooks, 25, 29, 35
Paper cups, in heat-loss experiment, 80
Paper towels, in studying change in rocket mass, 32
Pencil, 4
in construction of height measurer, 4–5
used with force measurer, 12
Plastic ruler, in construction of rocket test stand, 15–16
Plastic straws, 112, 115
in studying volcanic bulges, 115–116
in volcanic cinder cones study, 112–115
Plastic wrap, in lunar-gravity study, 106–107
Protractor, in construction of height measurer, 4–5
Pump, 1
caution note on use of, 9
used with plastic water rocket, 1–3

Quadrant, 5
  construction of, 4–5
  used to measure rocket height, 6–7

Rocket, plastic water, 1
  instructions for handling, 2
  launching, 2–4
  measuring height of launched, 6–7
Rocket test stand, 15
  construction of, 16
  in measuring water pressure, 16–18, 20–21
  push experiments with, 22–24
Rottenstone, 102, 110
  in liquid-impact study, 110–112
  in studying moon rays, 102–103
Rubber bands, in studying Newton's third law of motion, 43–46
Rubber stopper, used with force measurer, 11–12
Ruler, in construction of height measurer, 4–5
Ruler, plastic, in rocket test stand, 15–18

Sand, in studying moon craters, 92–99
Scissors, in construction of height measurer, 4–5
Screw clamp, in construction of rocket test stand, 15–16
Sinkers, in measuring shape change, 25–26
Spoon, in lunar-gravity study, 106–107
Steel balls, 51, 70, 92, 102
  in calculating horizontal speed, 51–56
  in operation of a pendulum, 70–73
  in studying moon craters, 92–99
  in studying moon rays, 102–105
String, 4, 35, 70
  in construction of height measurer, 4–5
Styrofoam balls, in determining length of moon day, 122–127

T pins, in determining length of moon day, 122–127
Tape, 35, 43, 70, 92, 106
Thermometer, heat loss experiments with, 80–81
Thread, 45, 92
  in studying moon craters, 92–99
  in studying Newton's third law of motion, 45–46
Twine, in calculating horizontal speed, 51–56

Washer, in construction of rocket test stand, 15–16
Water clock, in studying change in rocket mass, 32–35
Water-flow kit, in construction of rocket test stand, 15–16

1 2 3 4 5 6 7 8 9 10 81 80 79 78 77 76

What's Up?

Record Book

THE NATURAL WORLD MODULES/LEVEL 3

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Contents

To the Student	iv
Chapter 1/Up, Up, and Away	1
Chapter 2/What a Reaction!	3
Excursion 2-1/Newtons of Force	7
Chapter 3/How Much Is Needed?	8
Excursion 3-1/The Big Push	11
Excursion 3-2/One Stage at a Time	12
Chapter 4/All Systems Are Go	13
Excursion 4-1/Time to Fall	19
Excursion 4-2/The Falling Apple	19
Excursion 4-3/Orbiting Syncom	20
Excursion 4-4/Losing Heat	21
Chapter 5/Creating Craters	21
Excursion 5-1/Less Force	26
Chapter 6/Peaks and Flows	26
Chapter 7/A Day on the Moon	28
Excursion 7-1/An Excursion to the Far Side	30
How Am I Doing?	31
Self-Evaluations	32
Answer Key	51
My Progress	59
Resource Answer Pages	60

To the Student

This Record Book is where you should write your answers. Try to fill in the answer to each question as you come to it. If the lines are not long enough for your answers, use the margin, too.

Fill in the blank tables with the data from your experiments. And use the grids to plot your graphs. Naturally, the answers depend on what has come before in the particular chapter or excursion. Do your reading in the textbook and use this book only for writing down your answers.

Toward the end of this Record Book, you will find a set of Self-Evaluations for each chapter. Do these to check your progress. To check your answers to the Self-Evaluations, turn to the Self-Evaluation Answer Key in the back of this Record Book.

Answers provided are often completely dependent on local circumstances. In almost every instance, answers are of a quantitative nature and are based on measurements the students themselves make. In these cases, other answers may also be accepted. Be quite flexible as you assist your students with their attempts to answer questions. Answers are hardly ever as important as the process that generates them.

Chapter 1

Up, Up, and Away

☐ **1-1.** What angle did Observer A get? What angle did Observer B get?

(Both angles depend on rocket performance.)

☐ **1-2.** Did each observer get the same number of degrees?

No (probably not)

☐ **1-3.** If your answer to question 1-2 was No, what reasons can you give for the difference?

The rocket didn't go straight up; error made in measuring 25 m; error made in using quadrants; read scale incorrectly.

☐ **1-4.** What height corresponds to the angle measured by Observer A?

(Depends on rocket performance.)

☐ **1-5.** What height corresponds to the angle measured by Observer B?

(Depends on rocket performance.)

☐ **1-6.** What is the average of the two heights?

(Depends on rocket performance.)

PROBLEM BREAK 1-1

Procedure:

Expected results:

Data:

Conclusions:

☐ **1-7.** Describe how increasing the amount of water affects the height reached by the rocket.

(Descriptions will vary. Increasing the amount of water increases performance up to a certain point [75 ml] and beyond this point it decreases.)

☐ **1-8.** Describe how changing the amount of air affects the height reached by the rocket.

(Descriptions will vary. Increasing the amount of air increases the height reached. Best performance is attained with maximum air [20 strokes].)

☐ **1-9.** How does air, under pressure, and water cause an upward push on the rocket? Use the space provided to give your own ideas.

(Ideas will vary. Students may correctly say that air under pressure forces the water out and this gives an equal force on the rocket in the opposite direction. Or they may say that the air and water push on the air behind the rocket, making the rocket go up.)

Chapter 2

What a Reaction!

☐ **2-1.** Does the force measurer indicate that a force is acting when the pencil is in the stopper?

No

☐ **2-2.** Does the force measurer indicate that a force is acting when the pencil is removed?

Yes

☐ **2-3.** What was the direction of the force acting on the blade? Was it the same as, or opposite to, the direction of the air as it rushed out?

Opposite to

☐ **2-4.** How much force was acting?

0.1 N (Answers will vary.)

☐ **2-5.** Suppose the rocket has been loaded, has been pumped with air, and is ready for launch. Are the inside forces in balance?

Yes

☐ **2-6.** When the trigger release slide is pulled, the water rocket rises into the air. What unbalanced force acting on the water rocket causes it to move?

The upward force inside the rocket

☐ **2-7.** What could you do to increase this unbalanced force?

Increase the air pressure; increase size of the nozzle (make more water come out faster).

☐ **2-8.** Suppose you filled the rocket with water but pumped in no air, and then pulled the trigger release slide. Would the rocket rise?

No

☐ **2-9.** Suppose you added no water to the rocket, but pumped 15 strokes of air into it. Then you pulled the trigger release slide. Would there be any upward unbalanced force on the rocket?

Yes

PROBLEM BREAK 2-1

☐ **2-10.** As you opened the screw clamp, what happened to the plastic force-measurer blade?

It moved up.

☐ **2-11.** Why won't your newton scale work for the rocket test stand?

It is too stiff (the force is too small to bend it).

☐ **2-12.** Which jet tube gave a greater maximum-force point?

The one with the larger hole

☐ **2-13.** About how many times as great was the larger force than the smaller force?

About 2 times

☐ **2-14.** From which jet tube do you think more water flows in a given time?

From the jet tube with the larger hole

PROBLEM BREAK 2-2

Data:

Calculations:

☐ **2-15.** What is the average ml of water per second from the small jet?

1 ml/sec (varies)

☐ **2-16.** What is the average ml of water per second from the larger jet?

2 ml/sec (varies)

☐ **2-17.** About how many times as great was the amount from the larger jet than the amount from the smaller jet?

About 2 times

☐ **2-18.** How does the answer to question 2-17 compare with your answer to question 2-13?

They are the same.

☐ **2-19.** How did lowering the supply pail affect the maximum force?

The force decreased.

☐ **2-20.** What is the effect on the lift force of decreasing the pressure?

The lift force decreases as pressure decreases.

☐ **2-21.** What is the effect on the lift force of decreasing water speed?

The lift force decreases as speed decreases.

PROBLEM BREAK 2-3

☐ **2-22.** What force did you measure with the jet discharging underwater?

About 0.8 of the total force

☐ **2-23.** How did this force compare with the force measured with the jet out of the water?

It was less.

☐ **2-24.** How would you explain the difference in force if there was any?

An increase in pressure outside the nozzle (jet underwater) decreased the flow and therefore decreased the force.

☐ **2-25.** Do the results of this activity agree with the ideas of those people mentioned?

No

Excursion 2-1

Newtons of Force

☐ **1.** What happens to an object when an unbalanced force (a force that is not balanced by another force in the opposite direction) acts on it?

It changes shape or motion or both.

☐ **2.** What happens to the ball?

It falls, or changes motion (because of an unbalanced force—gravity).

☐ **3.** As the ball falls toward the floor, what happens to its speed?

It increases (because of an unbalanced force).

☐ **4.** When the ball hits the solid floor, what happens to it?

It stops and then rebounds.

☐ **5.** How must the upward elastic force on the ball compare with the force of gravity to make the ball bounce?

It must be greater.

☐ **6.** As the ball continues upward from the floor, what happens to its speed?

It decreases (because of an unbalanced force).

☐ **7.** About how much force in newtons did each sinker exert?

0.25 N

☐ **8.** How many sinkers did it take to exert a force of about 1 newton?

4

☐ **9.** What does the force measurer read?

1 N

☐ **10.** How many times more force can the thick blade measure than the thin blade can?

10 times

☐ **11.** What would you have to do?

Use a thinner blade.

☐ **12.** Describe how you would use the force measurer to measure upward forces.

Turn the force measurer over and zero the scale.

☐ **13.** If the nozzle is opened, will the forces be in balance?

No

Chapter 3

How Much Is Needed?

☐ **3-1.** What is the force-measurer reading in newtons?

About 0.36 N

☐ **3-2.** How many ml of water did you use to send the rocket to its greatest height?

(Answers will vary; probably about 75 ml.)

☐ **3-3.** What is the weight in newtons of the fueled rocket?

(Answers will vary; probably about 1.1 N.)

☐ **3-4.** If the rocket is to rise, and not just hang in space, what must happen?

There must be an unbalanced upward force.

☐ **3-5.** What was the average maximum force-measurer reading on rapid lift?

(Answers will vary; probably 3 to 4 N.)

☐ **3-6.** How does the rapid-lift force compare with the force of gravity on the fueled rocket? (Look back at your answer to question 3-3.)

It is greater (3 times as great).

☐ **3-7.** Suppose an upward force that is just equal to the weight of the rocket and its contents is applied. Would the rocket move upward? Explain your answer.

No. There must be an unbalanced upward force on the rocket. Otherwise it would just hover.

☐ **3-8.** Does the total mass of the rocket plus its contents remain constant throughout its flight? Explain your answer.

No. As the water exhausts from the nozzle, the total mass decreases until only the mass of the empty rocket remains.

☐ **3-9.** Did the speed of your cart in Activity 3-5 increase, decrease, or stay the same after you stopped pushing?

The speed decreased.

☐ **3-10.** Which track in Figure 3-2 indicates no change in cart speed? Which track indicates an increase in speed? Which track indicates a decrease in speed?

Track A indicates no change in speed. Track B indicates an increase in speed. Track C indicates a decrease in speed.

Table 3-1. Distances in the table will vary, depending on how hard the cart is pushed, the friction of the wheels, and the nature of the surface. Figures given here are examples only.

Table 3-1

Interval	Distance traveled (in cm)
1st	12.0
2nd	11.5
3rd	11.0
4th	10.6
5th	10.1
6th	9.7
7th	9.3

☐ **3-11.** What must have happened to the speed of the cart if (**a**) the distance between drops increases? (**b**) the distance between drops decreases? (**c**) the distance between drops stays the same?

(**a**) Speed must be increasing. (**b**) Speed must be decreasing. (**c**) Speed must be constant.

☐ **3-12.** With a constant force applied, did the cart gain speed, lose speed, or travel at a constant speed?

Gained speed

Table 3-2. Figures given here in the four distance columns are only for a guide. Student figures may differ widely from these. Note that the students were instructed to choose a section of the run where the force was maintained constant. Therefore, the 1st interval may have any dimension. The important thing is for the difference between intervals to be dependent on mass.

Table 3-2

	Distance (in centimetres)			
Time inverval	Total mass: 2.0 kg	Total mass: 1.5 kg	Total mass: 1.0 kg	Total mass: 0.5 kg
1st	2.0	2.0	4.0	4.0
2nd	2.3	2.4	4.5	4.9
3rd	2.6	2.7	5.0	5.9
4th	3.0	3.1	5.6	6.8
5th	3.2	3.5	6.1	8.0
6th	3.5	4.0	6.7	9.0

☐ **3-13.** Did the speed of the cart increase during each run?

Yes

☐ **3-14.** With which total mass did the speed of the cart change the fastest?

0.5 kg

☐ **3-15.** With which total mass was there the least change in speed?

2.0 kg

☐ **3-16.** Suppose you could continue to apply an unbalanced upward force on the rocket for a longer time. What would happen to it?

It would continue to speed up.

☐ **3-17.** When the rocket starts to fall back to the earth, what force is then unbalanced?

The force of gravity

Excursion 3-1

The Big Push

☐ **1.** What other forms of energy might be used to make matter shoot out of a rocket nozzle?

Heat, electrical, chemical, mechanical

☐ **2.** What is all matter composed of?

Particles

☐ **3.** All the different kinds of matter are made up of one or more of the 100 or so kinds of basic particles. What are these particles called?

Atoms

☐ **4.** During a chemical reaction, new combinations of atoms are formed. Where do the atoms in these new combinations come from?

From a rearrangement of the atoms in the original substances

☐ **5.** Which of the following are formulas representing elements? Which represent compounds? H_2O; Li; $CaCl_2$; HNO_3; N_2; Fe.

Elements: Li (lithium), N_2 (nitrogen), Fe (iron).

Compounds: H_2O (water), $CaCl_2$ (calcium chloride), HNO_3 (nitric acid).

☐ **6.** Energy changes cause particle rearrangements. Is it also true that particle rearrangements can produce energy changes?

Yes

☐ **7.** What must happen when the swiftly moving particles of the expanding gases strike the walls of the engine?

They put a force on the walls.

Excursion 3-2

One Stage at a Time

☐ **1.** Describe what happened to the cart when the thread burned.

The cart moved as the clay ball shot off.

☐ **2.** Which direction did the cart move in relation to the motion of the clay ball?

In the opposite direction

☐ **3.** How far did the cart move?

(Answers will vary, depending on the mass of the ball. Probably around 10 cm.)

☐ **4.** How far did the cart move this time?

(Answers will vary, but distance should be much less than that for question 3.)

☐ **5.** What is the effect of decreasing the speed at which the clay ball is thrown?

It decreases the distance the cart moves.

☐ **6.** How far did the cart move?

(Answers will vary. About half as far as for question 3)

☐ **7.** What is the effect of decreasing the mass of the ball that is thrown?

It decreases the distance the cart moves.

☐ **8.** From your investigation, what two things affect the amount of reaction acting on the cart?

Amount of mass thrown; speed that mass is thrown

☐ **9.** If the cart is at rest when the bricks are thrown, how will the speed of the cart change?

The speed will change from 0 to 10 m/sec.

☐ **10.** In what direction will the cart move?

In the direction opposite to the thrown bricks

Table 4-1

Trial	Force (newtons)	Distance (metres)
1	2	1
2	4	2
3	6	3
4	8	4
5	10	5

Table 4-1. Distance figures are given as a guide only. Student figures will differ and will be somewhat dependent on table height.

☐ **4-1.** Did the horizontal distance the ball traveled before hitting the floor seem to depend on the amount of force applied?

Yes

☐ **4-2.** What do you think would happen to the ball if you applied more and more horizontal force?

It would go farther and farther.

☐ **4-3.** The ball takes a certain length of time to reach the floor along trial path 1. How does that length of time compare with the length of time along trial paths 2, 3, 4, and 5?

They are the same.

☐ **4-4.** Did the balls strike the floor at about the same time?

Yes

☐ **4-5.** Did the distance that the one ball was projected make any difference in the time it took to reach the floor?

No

☐ **4-6.** What does this activity suggest about the time it takes for the ball to reach the floor along the various paths in Activity 4-4?

The times are the same.

☐ **4-7.** So far as you can tell, does the time to reach the floor depend on how fast the ball is moving horizontally?

No

☐ **4-8.** Does the time of flight seem to depend on the horizontal distance that the ball moves?

No

☐ **4-9.** What two motions does the ball have after the force is applied?

Horizontal and vertical

☐ **4-10.** Did the mass of the ball make a difference in time of fall?

No

PROBLEM BREAK 4-1

☐ **4-11.** What would happen to the ball?

It would orbit the earth (stay the same height above the earth's surface).

☐ **4-12.** Would the orbiting speed be the same, faster, or slower at a height 10 000 km above the earth?

Slower

Table 4-2

Table 4-2. Figures for orbiting speed are rounded out to two significant figures.

Height of satellite above surface (km)	Fraction of speed at surface of earth	Orbiting speed of satellite (m/sec)
0 (at surface)*	1.00	8000
160	0.99	7900
1000	0.92	7400
2000	0.86	6900
3000	0.82	6600
4000	0.78	6200
5000	0.74	5900
6000	0.71	5700
7000	0.68	5400
8000	0.66	5300
9000	0.64	5100
10 000	0.63	5000
380 000 (moon)	0.13	1000

*Consider this the same as 4.9 m above the surface.

☐ **4-13.** Use the data in the table and the grid in Figure 4-9 in your Record Book. Draw a graph of the change in weight with increased distance from the earth's surface.

☐ **4-14.** At what distance from the earth's surface is the weight of an object 0.5 of its weight at the surface (the place where it would weigh 50 N)?

About 2600 km

☐ **4-15.** At what distance is the weight 0.25 of its weight at the surface (the place where it would weigh 25 N)?

6500 km

☐ **4-16.** At what distance from the center of the earth is the weight 20 N (0.2 of what it is at the surface)?

About 14 200 km

☐ **4-17.** For the rocket to lift off the pad, how must the thrust force compare with the weight force of the loaded rocket?

The thrust must be greater than the weight.

☐ **4-18.** How will the amount of thrust produced by the engines at ground level compare with the thrust at higher altitudes?

The thrust at ground level will be less than the thrust at higher altitudes.

☐ **4-19.** As the rocket rises faster and faster, what force opposing its motion will increase to a maximum and then decrease?

The force of air drag, or friction

☐ **4-20.** What other force opposes the rocket motion and decreases as the rocket gets farther from the earth?

The force of gravity, or weight

☐ **4-21.** How many miles per hour is 8 km per second?

17 856 mi/hr

Figure 4-9

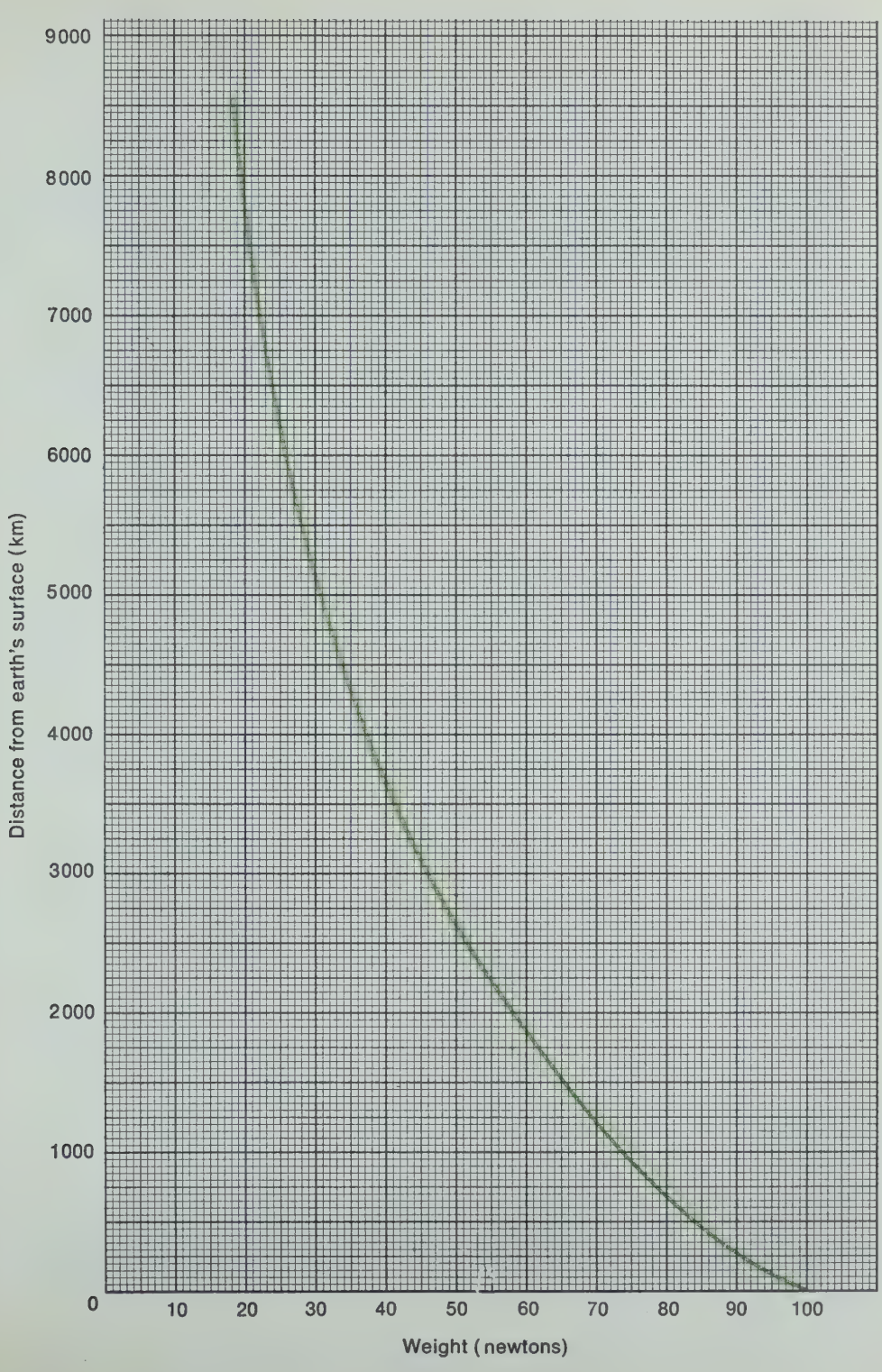


Figure 4-9. Because the distance figures in Table 4-3 were rounded off, they are not absolutely accurate. This means that there will be slight discrepancies in the graph and in answers for questions 4-14, 4-15, 4-16, which are dependent on the graph.

☐ **4-22.** The time needed for a satellite to go once around in its orbit is the *period* of that satellite. What is the earth's period as a satellite of the sun?

$365\frac{1}{4}$ days (1 year; 12 months; 8766 hours)

☐ **4-23.** How many seconds would it take for the object traveling at 8 km per second to make one trip around the earth? (The circumference of the earth is about 40 000 km.)

5000 sec

☐ **4-24.** What effect would a higher orbit have on the period of a spacecraft?

It would increase the period (make it longer).

☐ **4-25.** If a spacecraft is to stay in a moon orbit for a while, what must be done?

It must be slowed down.

☐ **4-26.** What must be done for a spacecraft to leave a moon orbit and get back to the earth?

It must be speeded up.

☐ **4-27.** When a force is applied to move something some distance, what is done?

Work

☐ **4-28.** When work is done, what else is involved?

Friction and heat energy

☐ **4-29.** When air resistance is present, what happens to the surroundings?

The temperature of the surroundings increases.

Excursion 4-1

Time to Fall

☐ **1.** What is the time (in seconds) for 10 complete swings?

20 sec

☐ **2.** What is the time (in seconds) for 1 complete swing?

2 sec

☐ **3.** What is the time (in seconds) for 10 complete swings?

20 sec

☐ **4.** What is the period of the pendulum (time for 1 complete swing)?

2 sec

☐ **5.** Compare the periods of the two objects.

They are the same.

☐ **6.** What is the length of time for 10 complete swings?

14 sec

☐ **7.** What is the period of the pendulum?

1.4 sec

☐ **8.** How does this period compare with the period that used a 1-metre length of string?

It is shorter (1.4 to 2).

☐ **9.** From your investigations, which of the variables affect the period of the pendulum?

Length of the pendulum

Excursion 4-2

The Falling Apple

☐ **1.** If no other force acts on the ball, what path will it follow?

A straight line

☐ **2.** How many earth radii is the apple from the center of the earth?

One earth radius

☐ **3.** How many times farther away is the moon than the apple from the center of the earth?

60 times

☐ **4.** What is the square of the number?

3600

☐ **5.** How many times faster will the apple fall toward the earth than the moon will fall?

3600 times faster

Excursion 4-3

Orbiting Syncom

☐ **1.** What must the period of the parking orbit be for a good communications satellite that stays over the same point?

24 hr

☐ **2.** The height of a satellite whose period is 24 hours is how many km?

36 000 km

☐ **3.** How does the period in question 2 compare with the period of a satellite in a parking orbit at a height of 161 km?

It is longer (24 hr to 86 min).

☐ **4.** How can this last statement be explained?

Fuel must be used to boost the satellite to 36 000 km. This is almost 7 earth radii from the center of the earth, and gravitational attraction is only 1/45 of what it was on the surface. Then it must be slowed down and inserted into orbit. To send it to the moon only requires giving it escape velocity and letting it coast the rest of the way.

Excursion 4-4

Losing Heat

☐ **1.** What is the temperature of the ice?

0 °C (or below)

☐ **2.** Did the temperature rise as the ice melted?

No

☐ **3.** What happened to the heat from the flame?

It went into the melting of the ice.

Chapter 5

Creating Craters

☐ **5-1.** If you were to look back at the earth from far out in space, would you be able to see the height of its mountains?

No

☐ **5-2.** What do you think could have caused the craters shown in Figures 5-6 and 5-7?

Meteorites, volcanic activity

☐ **5-3.** What might have produced the groove that runs through the crater in Figure 5-7?

Cracking of the moon's surface

☐ **5-4.** Which of these would you classify as impact craters? as volcanic craters?

Impact craters: 5-10, 5-12; volcanic craters: 5-9, 5-11

☐ **5-5.** What is the diameter of the crater?

4 cm

☐ **5-6.** Was material thrown out of the crater as the object hit?

Yes

☐ **5-7.** Is there a raised rim around the crater?

Yes

☐ **5-8.** Is the floor of the crater below the level of the surrounding surface?

Yes

☐ **5-9.** How many times greater is the diameter of the crater than the diameter of the ball?

3 times

☐ **5-10.** What is the diameter of the crater?

3 cm

☐ **5-11.** Compare the size of the crater formed by the glass marble with that formed by the steel ball.

The crater formed by the glass marble is smaller than the one formed by the steel ball (3 to 4).

☐ **5-12.** What is the diameter of the crater?

5 cm

☐ **5-13.** Compare the size of the crater formed by dropping the ball from 1 m with the one formed by the 50-cm drop.

The crater formed by the 1-m drop is larger than the one formed by the 50-cm drop (5 to 4).

☐ **5-14.** If the meteor crater is about 1200 meters in diameter, what do you predict was the diameter of the meteor that created it?

60 m

☐ **5-15.** Describe the appearance of the hill and the crater when lighted from the side.

When lighted from the side, the hill casts a shadow on the side away from the light. The crater rim casts a shadow into the crater that looks different from the shadow cast by the hill.

☐ **5-16.** How could you tell from which direction the light was coming if you saw a photograph of craters and mountains with shadows?

See which way the shadows are cast; the light would be coming from the opposite direction.

☐ **5-17.** In what way did a change to overhead lighting change the appearance of the features on the sand surface?

When the light shines straight down on the hill and the crater, there are no shadows, and it is harder to tell them apart. Details are lost.

☐ **5-18.** From which direction was the light coming in Figure 5-18, above or below?

From below

☐ **5-19.** Describe the effect of the sand's falling on the rim of the crater?

It softens the rim of the crater and wears down the sharp edges. It also partly fills the crater.

☐ **5-20.** How would constant bombardment of small particles affect the sharpness of the moon's features?

It would soften the features and wear down the sharp edges of various formations.

☐ **5-21.** Suppose a large object struck the surface near a crater. What do you predict would happen?

It would knock material into the crater.

☐ **5-22.** Was material thrown from the second crater into the first?

Yes

☐ **5-23.** Suppose you didn't know which crater was formed first. Could you tell, by the overlapping pattern, which crater is the older and which the younger? Explain your answer.

Yes. The older rim is knocked down, or interrupted, by the younger rim. The younger crater throws material into the older crater. The younger rim is more complete than the older one.

PROBLEM BREAK 5-1

Problem Break 5-1. Only a rough sketch was called for in the text. Therefore you probably should not expect an accurate drawing. Students should be able to identify hills and craters and show the relative crater age in at least one group.

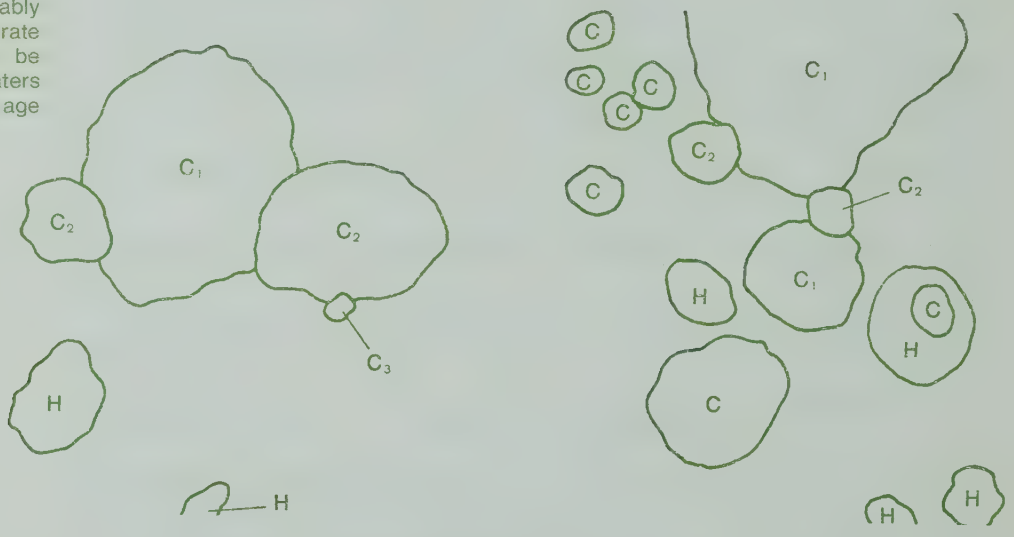


Figure 5-20

☐ **5-24.** Where do the materials that form the rays seem to have come from?

From the crater, below the surface

☐ **5-25.** Why, do you think, are the rays lighter colored than the surrounding area?

Material from below the surface may be lighter in color than the surface material.

☐ **5-26.** Was material thrown out of the crater?

Yes

☐ **5-27.** Did it form a ray system of a different color than the surface?

Yes

☐ **5-28.** Describe the paper after several minutes have passed and the objects have been removed.

The paper is lighter where the objects covered it and darker where the light rays hit it.

☐ **5-29.** Describe your observation of the crater that formed.

The crater had a raised rim, floor lower than the surrounding area, and bright rays extending out in all directions for up to twice the diameter of the crater.

☐ **5-30.** Do the rays that are formed resemble the ones from certain craters on the moon?

Yes

☐ **5-31.** How does gravity on the moon compare with that on the earth?

It is less (1/6 as much).

☐ **5-32.** How would air resistance on the moon compare with that on the earth?

There is no air resistance on the moon.

☐ **5-33.** Are dust dunes on the moon formed in the same way as the sand dunes on the earth? Explain your answer.

No. There is no air on the moon, and no water has yet been found there. So the dust dunes must have formed as a result of an impact (or in some other way).

Excursion 5-1
Less Force

☐ **1.** What is your weight on the earth?

(Answers will vary with students.)

☐ **2.** What would your weight be on the moon?

(Answers will vary. Should be 1/6 of answer for question 1.)

☐ **3.** What might happen to the pieces that shoot out into space from the moon?

They might be captured by the gravity of another body, such as the earth, and be pulled to the surface of the body.

☐ **4.** Describe the appearance of the particles.

(Answers will vary. With luck, it will be "small black spheres" and/or "small light-colored spheres.")

☐ **5.** When the Apollo 11 astronauts kicked moon dust with their boots, they noted that the particles went a long way before settling to the surface. How do you account for this?

With no air resistance, and gravity only 1/6 as much as on the earth, any particles that are given horizontal motion will not be slowed down or pulled to the surface rapidly. (That's why Alan Shephard hit a golf ball so far on the moon.)

Chapter 6
Peaks and Flows

☐ **6-1.** Describe the action of the surface of the water as the drop hits it.

It splashes.

☐ **6-2.** Can you identify any central peaks in the drop craters?

Yes

☐ **6-3.** If your answer to question 6-2 is Yes, did the most pronounced peaks form where the layer was thick, or thin?

Thick

☐ **6-4.** Use what you learned in this activity to explain why you think some craters on the moon have central peaks and others do not.

If the impact was greater, or the surface broken up to a greater depth, the surface material might have liquified more in some places than in others.

☐ **6-5.** How does the shape of the cone compare with the cinder cones in Figures 5-9 and 6-4?

It looks similar.

☐ **6-6.** Is the position of the crater in the mound similar?

Somewhat

☐ **6-7.** Is the shape of the crater similar?

In general, yes

☐ **6-8.** What is the position of the crater floor with respect to the surrounding area?

It is higher.

☐ **6-9.** What happened to the ejected material?

It fell on the surrounding area and on the cone.

☐ **6-10.** Describe the action of the bentonite as the balloon expands.

The bentonite swells upward, cracks, and flows around the shape of the balloon.

☐ **6-11.** Why is there no weathering effect on the moon's surface?

Because there is no atmosphere, wind, or water

PROBLEM BREAK 6-1

1. Apennine Mountains: The mountains could have been formed by a huge meteor when it formed the Sea of Rains.
2. Stadius: It is completely flooded with the mare material, so it formed before the mare.
3. Wallace: It isn't flooded as much as Stadius, and its rim is sharper.
4. Sea of Rains: The lava flowed into the entire area after the mountains were formed.
5. Seething Bay: If the lava flowed from the Sea of Rains, it reached the bay later.
6. Eratosthenes: It must have formed after the sea and the mountains, because it cuts into them.
7. Copernicus: Its rays cross all the other features in the photograph.

Chapter 7

A Day on the Moon

☐ **7-1.** From the observations you have made, list the things you might encounter at your landing site that could make the landing difficult.

Rough surface: craters and hills; dust; glare from the sun; dark surface; finding a level spot

☐ **7-2.** With this heavy suit, it would be somewhat difficult to walk around on the earth. Why would it be easier to walk on the moon?

The suit wouldn't weigh as much on the moon.

☐ **7-3.** How much of the earth's surface could be seen from the moon in this 24-hour period?

All of it

☐ **7-4.** How much of the moon's surface would an observer on the earth see during the 24-hour period?

Half of it

☐ **7-5.** Would the side of the earth that is toward the moon in Activity 7-2 be sunlit, or dark (moonlit)?

Dark (new earth)

☐ **7-6.** Would an observer on the earth see a full moon, a half moon, or a new moon (unlighted)?

Full moon

☐ **7-7.** As seen from the Styrofoam earth, how much of the moon is lighted?

Half

☐ **7-8.** As seen from a man at X on the moon, how much of the earth is lighted?

Half

☐ **7-9.** As seen from the earth, how much of the moon is now lighted?

None

☐ **7-10.** Where does the light come from that shines on the face of the moon, making it slightly visible?

The light is reflected from the earth.

☐ **7-11.** As seen from the earth, how much of the moon is lighted?

Half

☐ **7-12.** As seen from the moon, how much of the earth is lighted?

Half

☐ **7-13.** How many times did the moon rotate with respect to the sun during the $29\frac{1}{2}$ day period?

Once

☐ **7-14.** How long is a moon day from one sunrise until the next?

$29\frac{1}{2}$ earth days of 24 hours each

Excursion 7-1

An Excursion to the Far Side

☐ **1.** Why have they not been observed?

Because the other side is never facing toward the earth

☐ **2.** How does the age of the trough compare with the age of similar features on the front side of the moon?

It is younger than some, and older than others.

☐ **3.** What do you think could be the source of the dark material around the elongated crater?

It might be volcanic material brought up from the interior.

☐ **4.** What does the lack of large craters in the dark floor suggest?

It suggests that the dark floor was formed relatively recently.

☐ **5.** What do the many small craters in the floor of the large crater in Figure 6 tell you about the relative age of the basin?

It is relatively old.

How Am I Doing?

You probably wonder what exactly you are expected to learn in this science course. You would like to know how well you are doing. This section of the book will help you find out. It contains answers to the Self-Evaluations for each chapter. If you can answer all the questions, you're doing *very* well.

Self-Evaluations are for your benefit. Your teacher will not use the results to give you a grade. But you may want to grade yourself.

Some questions can be answered in more than one way. Your answers to these questions may not quite agree with those in the Answer Key. If you miss a question, review the material on which it was based before going on to the next chapter. Page references are frequently included in the Answer Key to help you review.

On page 59 of this booklet, there is a grid that you can use to keep a record of your progress.

TO THE TEACHER The following sets of questions have been designed for self-evaluation by your students. The intent of the self-evaluation questions is to inform the student of his or her progress. The answers are provided for the students to give them positive reinforcement. For this reason it is important that each student be allowed to answer these questions without feeling the pressures normally associated with testing. We ask that you do not grade the student on any of the chapter self-evaluation questions or in any way make the student feel that this is a comparative device.

The student should answer the questions for each chapter as soon as the student finishes the chapter. After answering the questions, the student should check his or her answers immediately by referring to the appropriate set of answers in the back of the Record Book.

There are some questions that require planning or assistance from the classroom teacher or aide. Instructions for these are listed in color on the pages that follow. You should check this list carefully, noting any item that may require your presence or preparation. Only items that require some planning or assistance are listed.

You should check occasionally to see if your students are completing the progress chart on page 59.

SELF-EVALUATION 1

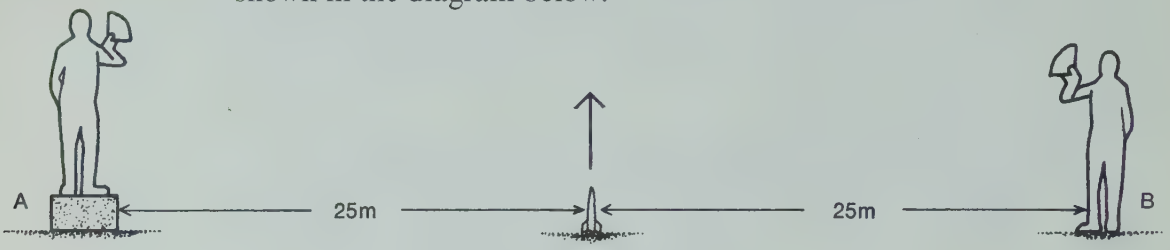
1-1. Identifies the one factor that best measures performance of a water rocket.

☐ **1-1.** If you were interested in comparing the performance of two water rockets, which of the following would be the best factor to measure in making the comparison? Check the best answer.

_____ **a.** The weight of the rockets.
_____ **b.** The length of the rockets
_____ **c.** The height reached by the rockets
_____ **d.** The angle at which the rockets are launched

1-2. Explains why variables must be controlled in measuring rocket height.

☐ **1-2.** Two students observe a rocket launched from the positions shown in the diagram below.



When the rocket is launched, will both students record the same height for the rocket? Explain your answer.

_____

_____

_____

_____

Use the table below to answer questions 1-3 to 1-5.

HEIGHT CONVERTER FOR OBSERVER AT 25 METRES

Angle	0°	5°	10°	15°	20°	25°	30°	35°	40°
Height	0 m	2.2 m	4.4 m	6.9 m	9.1 m	11.7 m	14.4 m	17.5 m	21.0 m
Angle	45°	50°	55°	60°	65°	70°	75°	80°	85°
Height	25.0 m	29.8 m	35.7 m	43.3 m	53.6 m	68.7 m	93.3 m	141.8 m	285.8 m

1-3. Calculates the height of a rocket, given distance from launch, sighting angle, and the table.

☐ **1-3.** If an observer 25 m from the launch site measured an angle of 60° for the height of a rocket, how high did the rocket go?

_____

☐ **1-4.** Two observers were 25 m from the launch site of a rocket. One observer measured an angle of 40° for the height of the rocket, and the other observer measured an angle of 35°. What height should be reported for the rocket? Explain your answer.

1-4. Explains the advantage of averaging several measurements instead of using a single measurement

_____

_____

☐ **1-5.** Ask your teacher's permission to go outside. Take your quadrant and a metrestick outside and measure the height of the school building in degrees. Use the height-converter table to change your measurement to metres.

1-5. Demonstrates the use of a quadrant, metrestick, and table.

1-5 You should have a reasonably accurate height figure for checking students' answers

_____

☐ **1-6.** What two variables influenced how high your water rocket went?

1-6. Names the two variables that control rocket performance.

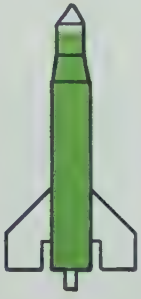
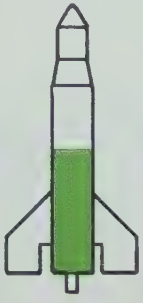
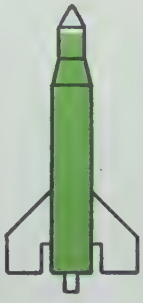
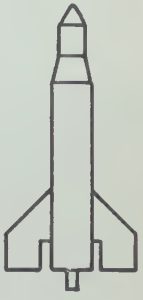
_____

_____

☐ **1-7.** Which of the rockets shown in the chart will reach the greatest height when launched?

1-7. Identifies how the two variables that control rocket performance interact.

_____

	A	B	C	D	E
					
Pressure	8 strokes	8 strokes	6 strokes	6 strokes	8 strokes
Water level	Almost full	½ full	½ full	Almost full	No water

1-8. Identifies what must be done in constructing a measuring instrument to make it usable.

☐ **1-8.** You constructed a quadrant to measure rocket height. As with any measuring instrument, what two things need to be provided to make the quadrant usable? Check the correct answers.

_____ **a.** Zero point and height measurements
_____ **b.** 180° section of circle and hand grip
_____ **c.** Calibrated scale and zero point
_____ **d.** Height measurements and calibrated scale

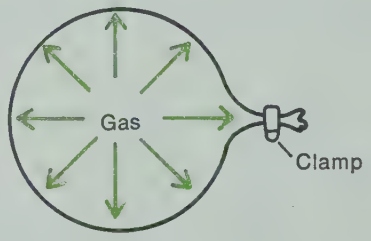
SELF-EVALUATION 2

If you did the excursion for this chapter, write its number here.

_____

2-1. Identifies the cause of motion of an object.

☐ **2-1.** Draw an arrow by the diagram below to indicate in which direction the balloon would move if the clamp were released.



2-2. Identifies the relationship between rocket thrust and mass of matter ejected per second.

☐ **2-2.** Check the correct answer. If you increase the mass of matter rushing out through a rocket nozzle each second, the thrust of the rocket will

_____ **a.** decrease.
_____ **b.** increase.
_____ **c.** stay the same.

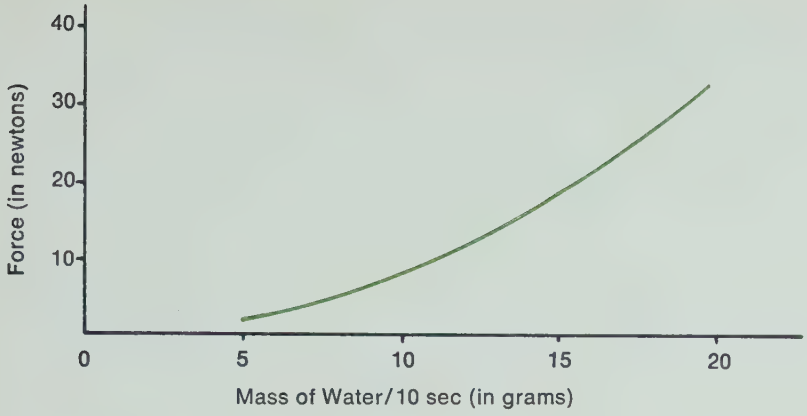
2-3. Identifies the relationship between speed of the matter ejected from the rocket and rocket thrust.

☐ **2-3.** Check the correct answer. If you decrease the speed of the matter rushing out through a rocket nozzle, the thrust of the rocket will

_____ **a.** decrease.
_____ **b.** increase.
_____ **c.** stay the same.

☐ **2-4.** Use the graph below to answer the following questions.

2-4. Uses graphs to find the relationship between variables.



a. When 10 grams of water rush from the jet in 10 seconds, what is the force in newtons on the jet?

_____

b. How many grams of water would have to rush from the jet in 10 seconds to produce a force of 30 newtons on the jet?

_____

c. Predict what the force on the jet will be when 25 grams of water rush from the jet in 10 seconds.

_____

☐ **2-5.** A water rocket was launched straight up from a submarine on the bottom of the ocean. An identical water rocket was launched straight up on land. Which of the rockets produced the greater upward thrust during the first second after launch? Explain your answer.

2-5. Explains the effect of outside substances on rocket thrust.

_____

_____

_____

_____

2-6. Recognizes what a force is, and how it can be measured.

☐ **2-6.** Check the correct answer. A force is

_____**a.** a push.

_____**b.** a pull.

_____**c.** something that can be measured by the deflection of a force-measurer blade.

_____**d.** all of the above.

SELF-EVALUATION 3

If you did any excursions for this chapter, write their numbers here.

_____

3-1. Calculates the total weight of a rocket.

☐ **3-1.** The weight of an unfueled spacecraft is 28 500 000 N. The weight of its fuel and oxygen is 21 000 000 N. What is the total weight that must be lifted by the thrust of the rocket engines?

_____

3-2. Explains the relationship between upward thrust and downward force on rocket motion.

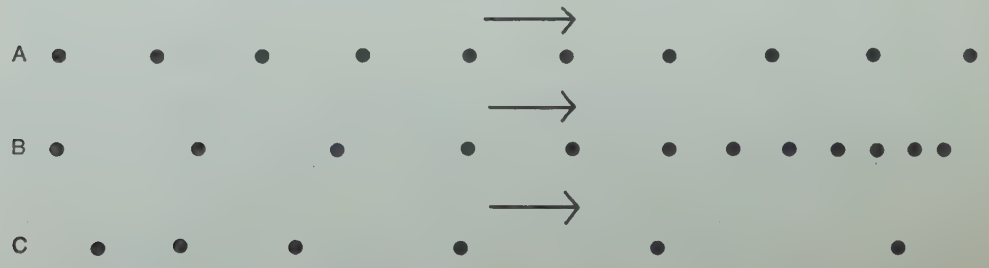
☐ **3-2.** A rocket is resting on its launch pad. If the upward thrust of its engines were equal to the downward force on the rocket, would the rocket rise off the launch pad? Explain your answer.

_____

_____

_____

Use the diagram that follows to answer questions 3-3, 3-4, and 3-5. The drop patterns shown were obtained from an experiment with a water-clock cart. The arrows indicate the direction in which the cart was moving.



☐ **3-3. a.** Which pattern indicates an increasing speed for the cart?

3-3. Identifies water-drop patterns with varying speeds of ■ cart.

_____

b. Which pattern indicates a decreasing speed for the cart?

_____

c. Which pattern indicates a constant speed for the cart?

_____

☐ **3-4.** What is the average distance in millimetres between the drops in pattern C?

3-4. Calculates average distance.

_____

☐ **3-5.** Which pattern indicates that the cart is being pushed or pulled by a constant unbalanced force acting in the same direction as that in which the cart is traveling?

3-5. Infers the relationship between water-drop pattern and unbalanced force.

_____

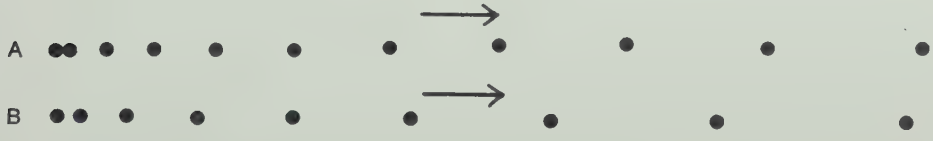
☐ **3-6.** If an unbalanced force, in the direction of motion, is continuously applied to a rocket in space, what happens to the speed of the rocket?

3-6. Describes the effect of an unbalanced force on rocket speed.

_____

☐ **3-7.** Use the diagram and information given to answer the questions that follow. The drop patterns were obtained from an experiment with a water-drop cart. The arrows indicate the direction in which the cart was moving.

3-7. Explains the effect of changing one variable at ■ time in ■ speed, mass, and force relationship.



a. The student who performed the experiment exerted the same unbalanced force of 0.2 N during each run, changing the mass of the cart between runs. The student forgot to write down which mass was which. During which run was the mass larger?

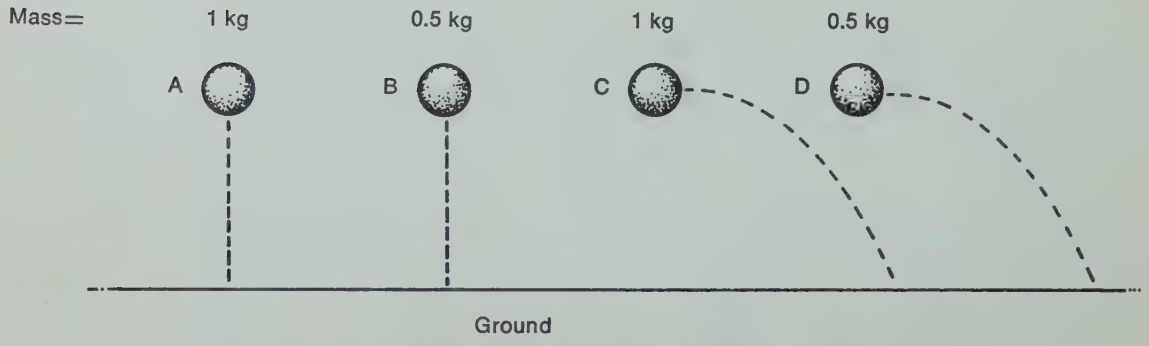
_____

b. Explain your answer.

SELF-EVALUATION 4

If you did any excursions for this chapter, write their numbers here.

Four balls of different masses are equally distant from the earth. Balls A and B are allowed to fall freely to the earth. Balls C and D are projected sideways with equal speeds. The path of each ball is shown below. Use these data and the diagram to answer questions 4-1 and 4-2.



4-1. Explains the factors that control the time for a body to fall some distance.

☐ **4-1. a.** If all the balls were released or projected at the same time, which ball(s) would hit the ground first?

b. Explain your answer.

_____

_____

_____

☐ **4-2. a.** Which ball(s) would travel farthest?

4-2. Explains the relationship between horizontal speed and distance traveled of a falling body.

_____

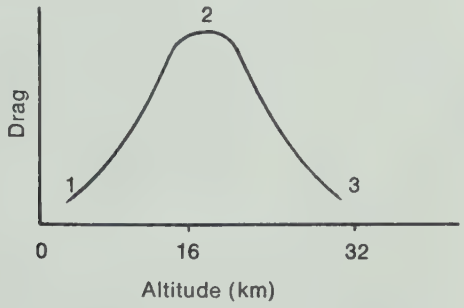
b. Explain your answer.

_____

_____

☐ **4-3.** The graph shows the change in air resistance (drag force) on a rocket as its altitude increases.

4-3. Explains how drag force (air resistance) on a rocket varies with altitude and speed.



a. Why does the air resistance increase so rapidly during the first 16 km?

_____

_____

b. The drag force on the rocket reaches a maximum at a point called max-Q. Which point (1, 2, or 3) on the graph is max-Q?

_____

c. At which point (1, 2, or 3) is the speed of the rocket greatest?

_____

d. Why does the drag force decrease so rapidly after the first 16 km?

4-4. Defines period of a satellite.

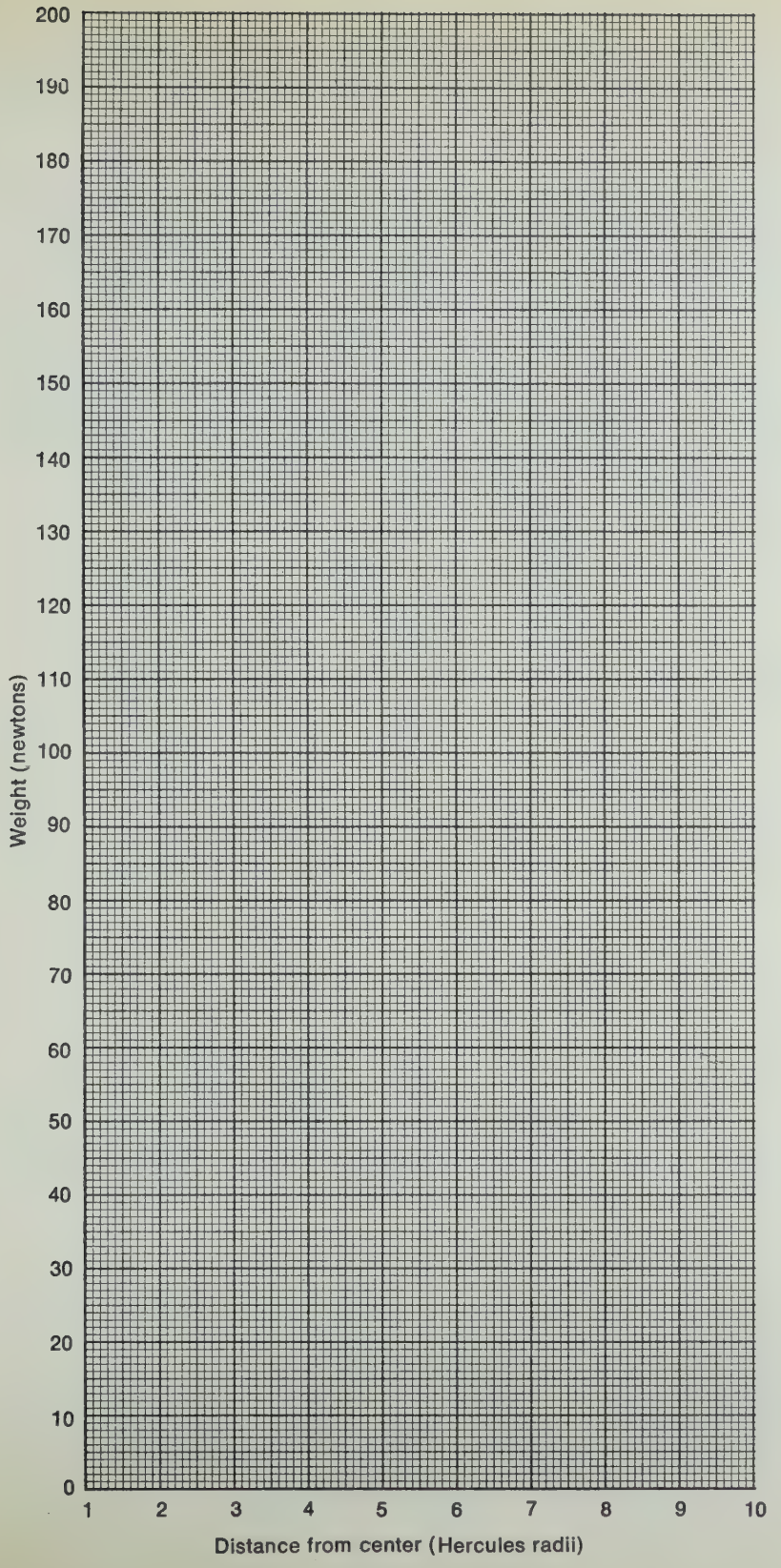
☐ **4-4.** What is meant by the *period of a satellite?*

Use the following to answer questions 4-5 and 4-6. Assume that there is a planet called Hercules in our solar system. Hercules is similar to the planet Earth, except that Hercules has a radius of 2000 km while Earth's radius is 6400 km. The following data have been obtained about Hercules.

Distance from the center of Hercules in Hercules radii (r)	Weight of object that exerts a 200-N force at surface (N)
1	200.0
2	50.0
3	22.0
4	12.6
5	8.0
6	5.6
7	4.0
8	3.2
9	2.4
10	2.0

4-5. Demonstrates the ability to draw a graph.

☐ **4-5.** Using the preceding data and the grid on page 41, plot a graph of the weight of the object as a function of its distance from the center of Hercules as measured in Hercules radii.


200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Weight (newtons)
1
2
3
4
5
6
7
8
9
10
Distance from center (Hercules radii)

4-6. Demonstrates the ability to read data from a graph.

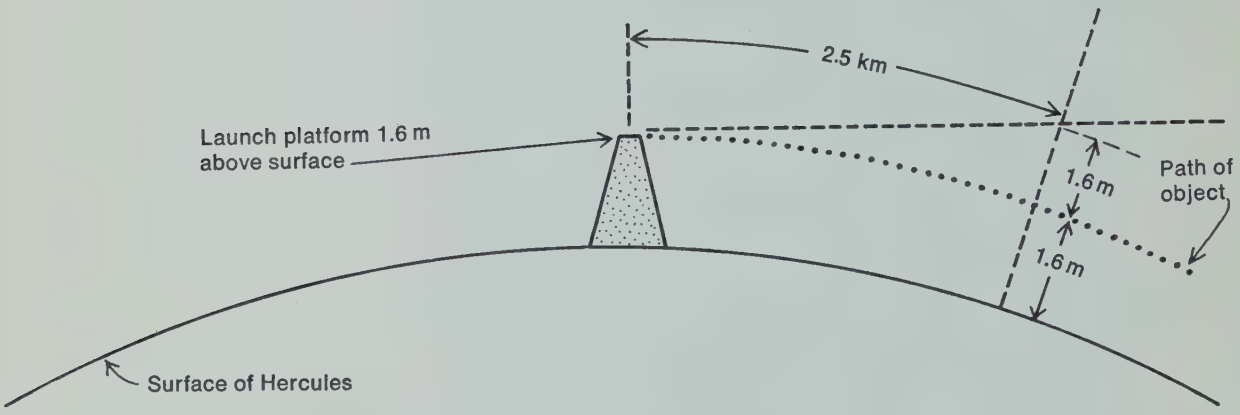
☐ **4-6. a.** At what distance from the center of Hercules does the object's weight become 0.25 of its weight at the surface (50 N)?

_____

b. When the object is located at 5 radii, it has what fraction of its weight at the surface?

_____

At the surface of Hercules, an object falls 1.6 m in the first second after its launch. For every 2.5 km of distance, Hercules curves downward 1.6 m at the surface. Use this information and the diagram to answer questions 4-7 and 4-8.



4-7. Calculates orbiting speed.

☐ **4-7.** What would be the orbiting speed for an object on Hercules?

_____

4-8. Relates orbiting speed to height.

☐ **4-8.** At a height of 10 000 km above Hercules, would the orbiting speed be faster than, the same as, or slower than the speed at a height of 1.6 m?

_____

4-9. Relates gravitational attraction to height of orbit.

☐ **4-9.** Two satellites of equal mass are orbiting the earth. The radius of the orbit of satellite A is twice that of satellite B.

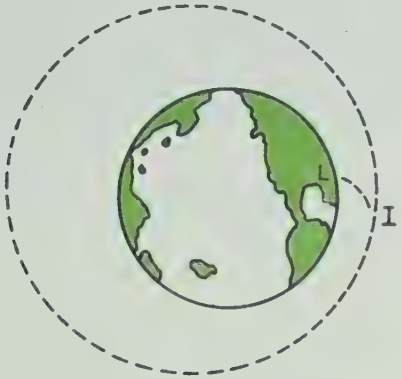
a. Is the period of satellite A less than, greater than, or equal to the period of satellite B?

_____

b. Is the gravitational pull of the earth on satellite A less than, greater than, or equal to the gravitational pull of the earth on satellite B?

☐ **4-10.** The diagram below shows the path of a rocket that was launched at point L and inserted into orbit at point I.

4-10. Relates speed to orbit shape of a satellite



Was the speed of the rocket when it was inserted into orbit less than, equal to, slightly greater than, or much greater than the speed necessary to put the satellite into a circular orbit around the earth?

☐ **4-11.** Check the correct answer. When a satellite re-enters the denser earth atmosphere and is slowed down,

4-11. Identifies the effect of air resistance on a satellite and its surroundings.

_____**a.** only the satellite heats up.
_____**b.** only the surrounding air heats up.
_____**c.** both the satellite and the surrounding air heat up.
_____**d.** there is no other effect on the satellite.

If you did the excursion for this chapter, write its number here.

SELF-EVALUATION 5

5-1. Relates the incident angle of light to perceived shapes of features.

☐ **5-1.** Most professional photographers prefer to take pictures in the early morning or in the late afternoon. On the basis of your experiences while studying this chapter, explain why they prefer these times.

_____

_____

_____

5-2. Names the two variables that affect the amount of energy of a moving object.

☐ **5-2.** What two variables affect the amount of energy that a moving object has?

_____

Use the diagram below, which shows two craters formed in sand by falling objects, to answer questions 5-3 and 5-4.

A B

5-3. Relates crater size to speed of impact.

☐ **5-3.** Suppose the craters were formed by two steel balls that had the same mass. Which crater was formed by the ball that had fallen farther?

_____

5-4. Relates crater size to mass of impacting object.

☐ **5-4.** Suppose the two craters were formed by dropping balls of different masses from the same height. Which crater was the one that would have been formed by the ball with the greater mass?

_____

5-5. Distinguishes between crater types.

☐ **5-5.** What are two characteristics of impact craters that would help you distinguish them from other types of craters?

_____

_____

☐ **5-6.** Use the picture above to answer the questions that follow.

5-6. Infers relative age of craters.

a. Which crater is older?

_____

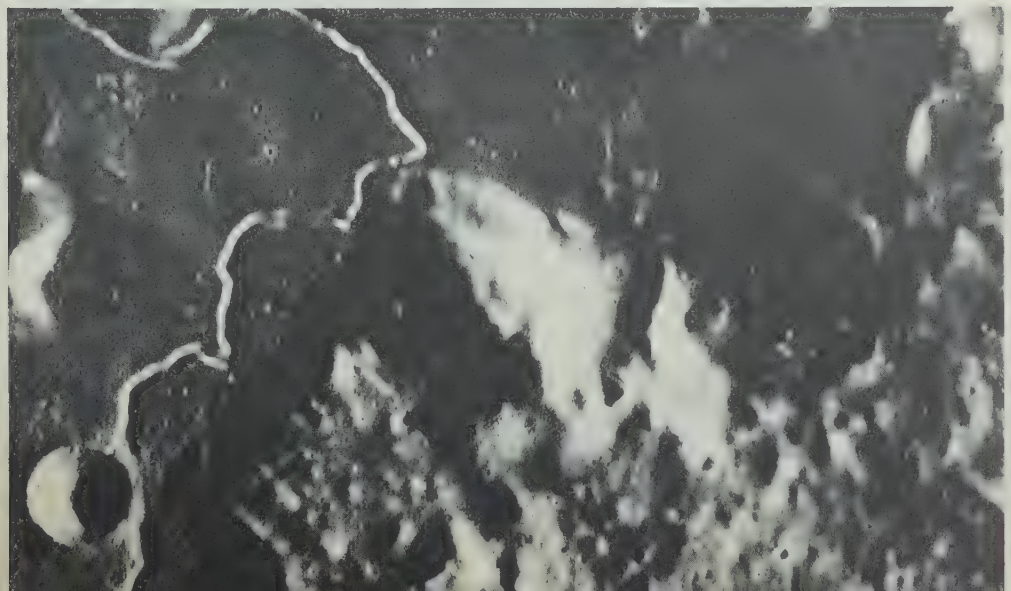
b. Explain your answer.

_____

_____

☐ **5-7.** On the moon photograph below, label the hills (H) and the craters (C).

5-7. Distinguishes features by shadows cast.



5-8. Uses modeling to explain features on the moon.

☐ **5-8.** What is a possible cause of the rays on the surface of the moon?

_____

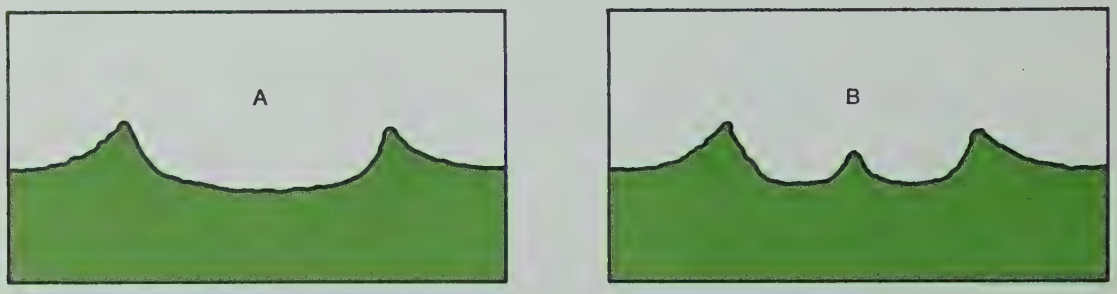
_____

_____

SELF-EVALUATION 6

6-1. Uses dropping water to model central peak formation on the moon.

☐ **6-1.** Use the diagram below, which shows a cross-sectional view through two impact craters, to answer the questions that follow.



a. Which crater was formed by the impact of an object that caused both the surface and the object to become molten when it hit?

_____

b. Explain your answer.

_____

_____

_____

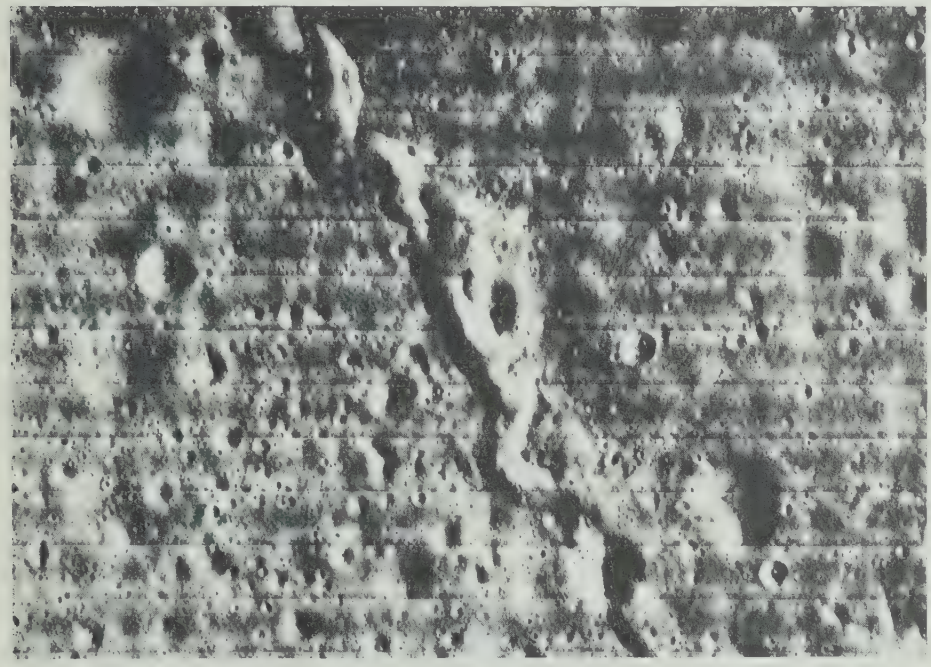
6-2. Describes the characteristics that distinguish volcanic craters from impact craters.

☐ **6-2.** What things would you look for in a picture of a crater if you were asked to determine whether the crater was a cinder-cone crater

formed by a volcano or whether it was an impact crater?

☐ **6-3.** Use the photograph to answer the question that follows.

6-3. Uses modeling to explain the formation of features on the moon.



The photograph shows a ridge of rock on the surface of the moon. What is a possible cause of this bulge in the surface?

6-4. Distinguishes between modification of features on the earth and on the moon.

☐ **6-4.** On earth, features are changed by weathering. Explain how features may be changed in the same or a different way on the moon.

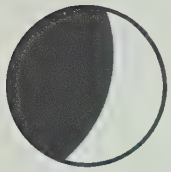
SELF-EVALUATION 7

If you did the excursion for this chapter, write its number here.

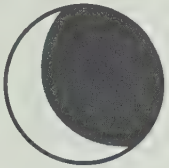
7-1. Uses a model of the sun-earth-moon system.

☐ **7-1.** Use the diagram below, which shows the positions of the earth, moon, and sun, to answer the questions that follow.

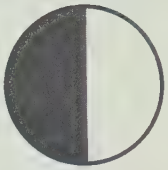
a. Check the diagram below that best represents what the moon would look like to an observer on the earth. (The shaded part of each diagram is the dark part of the moon that the observer would not see clearly.)



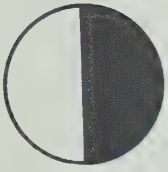
A _____



B _____



C _____



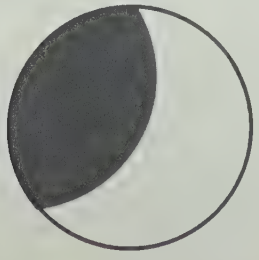
D _____

E _____

b. Would an observer on the moon at point X be able to see both the sun and the earth?

☐ **7-2.** On the diagram of the moon shown below, draw an arrow to point to the terminator.

7-2. Identifies the terminator on a heavenly body.



7-3. Explains the earth-moon system.

☐ **7-3.** Why doesn't a person on the earth ever see the far side of the moon?

_____

_____

_____

7-4. Recalls the period of the earth around the sun.

☐ **7-4.** What is the period of the earth around the sun?

_____

SELF-EVALUATION 1

1-1. The height reached by the rockets (c). Remember that these are water rockets and you want to compare their performance.

1-2. No, they won't measure the same height. The quadrant held by student A is higher than the quadrant held by student B. Since A and B are the same distance from the launch site but A's quadrant is higher, A will most likely measure a smaller angle. When consulting the height-converter table, A will then record a smaller height. If the student who is launching the rocket sends it off so that the flight is not straight up, no one can predict any of the angles. If you aren't sure about this, you should review text pages 6 and 7.

1-3. You should have found the height to be 43.3 m. Take another look at the table if you had problems.

1-4. The calculated height should be about 19.25 m. This is the average of the two heights of 21.0 m and 17.5 m found by the two observers. If you stop to think about how you measured the angles, you might agree that it would be reasonable to round off the answer to 19.3 m, or even 19 m.

1-5. Compare your answer with the answer that other students got. If your answer seems to be different from theirs, review text pages 7 and 8. Check your answer with your teacher.

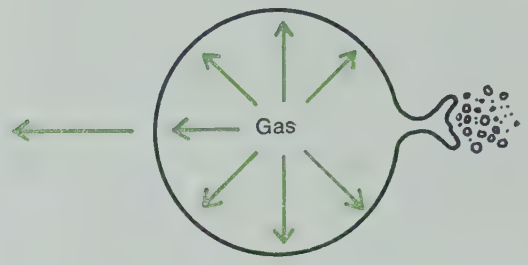
1-6. Your answer should include the amount of water you poured into the rocket and the amount of air you pumped into the rocket. You could also have included other variables, such as the angle at which the rocket was launched. If you did not include the first two variables mentioned, review Problem Break 1-1.

1-7. Rocket B will reach the greatest height. If you chose the wrong rocket, review your data from Problem Break 1-1. Perhaps you might like to try the various combinations pictured to be sure of the answer.

1-8. Calibrated scale and zero point (c). Every usable measuring instrument must have these.

SELF-EVALUATION 2

2-1. As the air rushes out of the balloon in one direction, the balloon moves in the opposite direction. If you have never tried this, you may want to do so at home. Maybe you can even determine the reason why the balloon does not travel in a straight path the way the rocket does. Do tail fins help?



2-2. Increase (b). Look at Problem Break 2-2 if you missed this one. You might even try to devise an experiment that uses a liquid other than water to see what happens when you keep the rate of flow constant but change the mass of the liquid that emerges from the jet each second.

2-3. Decrease (a). Think about what would happen if the water emerged slower and slower from your water rocket. How much thrust would there be if the water stopped emerging? Review Problem Break 2-2 if you are still having difficulty.

2-4. a. The force should be about 8 N. If you were off by a small amount, don't worry about it. However, if your answer was smaller than 6 N or larger than 10 N, look at the graph again.

b. To get a force of 30 N, you need a flow of about 18 g/10 sec.

c. You should have predicted a force of about 50 N. This process of extending the curve to predict what will happen is called "extrapolation." It is a useful process, but it can cause problems. For example, suppose the water flow was increased to 25 g/10 sec and the pressure broke the plastic nozzle. Then the prediction of 50 N would be wrong.

2-5. The water rocket that is launched on land will have a much greater thrust. Your work in Problem Break 2-3 should have shown you that as you increase the pressure outside the nozzle, the thrust decreases. The pressure outside reduces the amount of mass ejected per 10 sec and the speed at which it is ejected. At the bottom of the ocean the pressure outside the rocket would be so great that it would be unlikely for any water to be ejected from the rocket. If you had difficulty with this question, read Problem Break 2-3 again and check your data.

2-6. All of the above (d). "Push" and "pull" are common names for a force. The operational definition of a force is "something that changes the shape or the motion of another object."

SELF-EVALUATION 3

3-1. The rocket's thrust must be enough to lift both the spacecraft and the fuel it contains. Since the unfueled spacecraft weighs 28 500 000 N and the fuel weighs 21 000 000 N, the total weight lifted by the thrust of the rocket engines is 49 500 000 N. Read text pages 29 and 30 again if you had a different answer.

3-2. No. the rocket would not lift off unless there was an upward unbalanced force acting on it. If the thrust of the engines just equaled the weight of the rocket, the forces would be balanced and the rocket would not move. The thing to remember is that unless an unbalanced force acts on an object, it moves with a constant speed (which might be a speed of zero) in a straight line. If you had problems with this, do Activities 3-1 to 3-3 again and read over page 32.

3-3. a. Pattern C shows an increasing speed. The drops were being placed farther and farther apart.

b. Pattern B indicates a decreasing speed. As the cart traveled along, the drops were being placed closer and closer together.

c. Pattern A indicates that the cart was traveling at a constant speed. The cart was traveling the same distance between drops.

3-4. The average distance between drops is 18 mm. This is the average of measurements of 5, 11, 15, 21, 25, and 31 mm. If you did not get these measurements, check that you measured from the center of one dot to the center of the next dot.

3-5. Pattern C indicates a cart that is being pushed or pulled by a constant unbalanced force. If you chose pattern B, you were almost right. In pattern B there is a constant unbalanced force, but this time it is acting in the opposite direction of the motion of the cart. If you had difficulty with these questions, you should look at your data from Activities 3-4 to 3-9. You might read pages 33 to 36 in the text as well.

3-6. As long as there is an unbalanced force acting in the same direction the rocket is traveling, the speed of the rocket will increase.

3-7. a. The mass was larger for run A. If you look at the dot patterns for the two runs, you can see that the dots are closer together in run A. This means that the speed is not increasing as rapidly.

b. Your explanation should have included the idea that since the speed of the cart is not increasing as rapidly during run A as during run B, even though the same force is acting, the mass must be larger during run A. Try Activity 3-10 again if your answer did not include the ideas suggested above.

SELF-EVALUATION 4

4-1. a. All the balls would hit the ground at the same time.

b. Your answer should have indicated that the time of fall is determined only by the vertical distance from the ground, *not* by the mass of the object or its horizontal speed. Try Activities 4-1 to 4-8 again if you had difficulty with this question.

4-2. a. Balls C and D will travel farthest.

b. Since C and D have a horizontal speed when they start to fall, the paths they travel are longer than the paths of A and B. Remember, they travel farther but it takes them the same amount of time because their speed is faster.

4-3. a. During the first 16 km the rocket is picking up speed quite rapidly. Since the air resistance depends on the speed, the air resistance increases quite rapidly. Read pages 59 and 60 in the text for a more complete explanation.

b. Point 2 is max-Q. At point 2 the drag reaches its peak. That means this must be the point of max-Q.

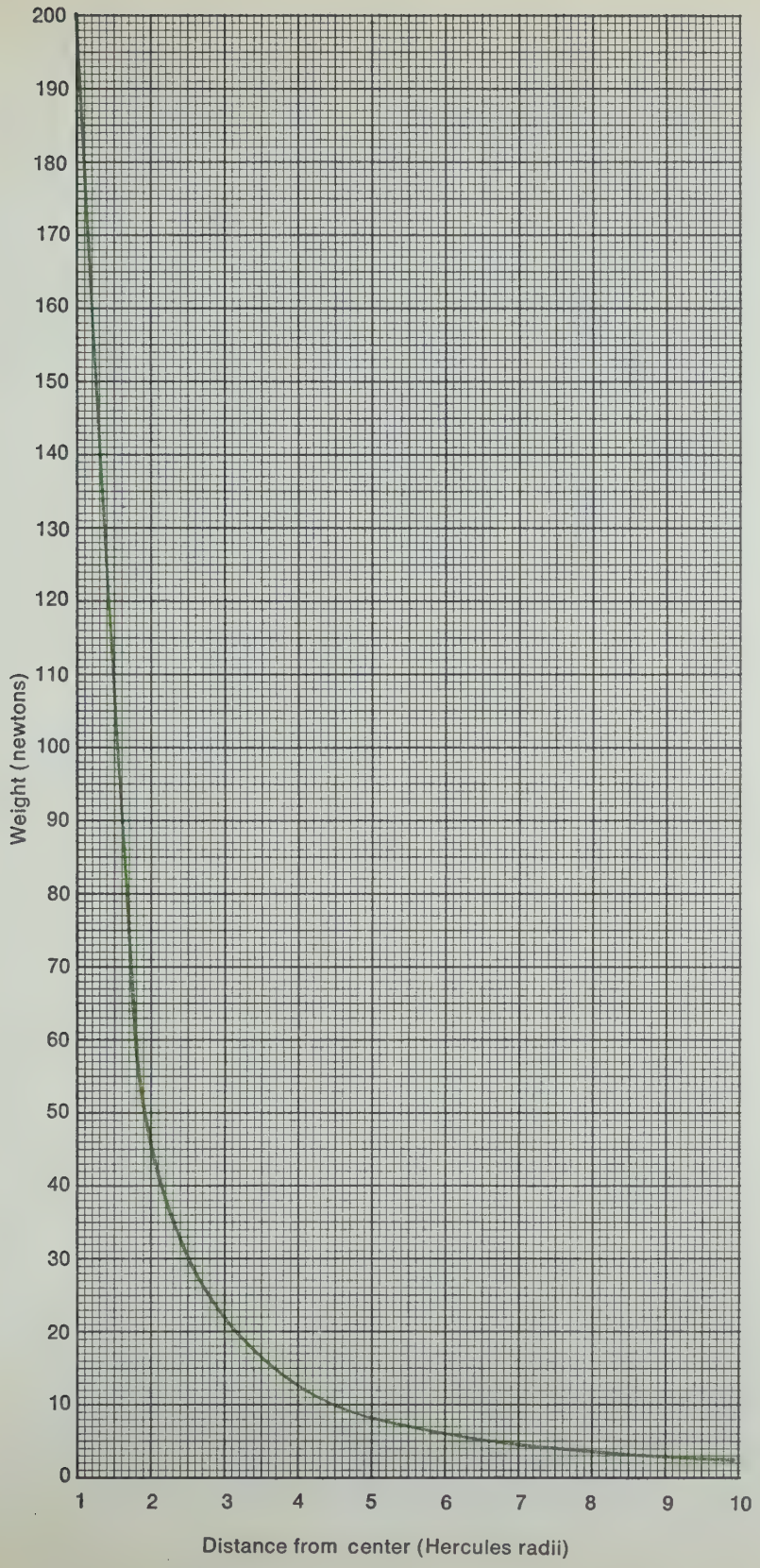
c. The rocket is traveling most rapidly at point 3. Remember that a large rocket's speed increases steadily as it climbs through the atmosphere.

d. As you get higher and higher in the atmosphere, the air gets thinner and thinner. This means that there are fewer air particles to rub against the rocket surface to produce air resistance.

4-4. The period of a satellite is the amount of time required for a satellite to make one complete orbit. For satellites in parking orbit, the period is about 88 minutes. You might look at page 64 in the text if you didn't remember the answer to this question.

4-5. The graph is shown on the next page.

4-6. a. When the object is at 2 radii, its weight is 0.25 of its weight at the surface of Hercules. You should have been looking for the distance where the object's weight was 200 N $\times$ 0.25 = 50 N. Read page 63 again if you missed this question.


200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Weight (newtons)
1
2
3
4
5
6
7
8
9
10
Distance from center (Hercules radii)

b. At 5 radii its weight will be 0.04 of its weight at the surface. Look at your graph. The object weighs 200 N at the surface. At 5 radii the same object has a weight of 8 N. Thus its weight is 8/200, or 0.04, as great as it is at the surface.

4-7. The orbiting speed at the surface would be 2.5 km/sec. This is similar to the calculation on text pages 57 and 58.

4-8. The orbiting speed would be slower. Remember that the farther a satellite is above the surface, the slower it has to travel.

4-9. a. The period of satellite A is greater than the period of satellite B. If you had difficulty with this question, read text pages 63–65.

b. The gravitational pull on satellite A is less than the pull on satellite B. Look at the graph you drew for question 4-5 if you had problems answering this question.

4-10. Slightly greater than. Look again at the possible paths of a satellite shown on text pages 65–67 if you missed this question.

4-11. Both the satellite and the surrounding air heat up (c). The heat on the satellite is high enough to melt away some of the nose cone. The heating of the surrounding air is great enough to ionize it, destroying radio communication between the satellite and the ground.

SELF-EVALUATION 5

5-1. These times are preferred because the longer shadows cast by the sun in the early morning and late afternoon reveal more details and texture in surfaces than the short shadows cast around noon. If you take photographs, this is something to keep in mind and try out. Repeat Activities 5-7 and 5-8 if you missed this question.

5-2. You should have indicated that the mass and the speed affect the energy of a moving object.

5-3. Crater B was formed by the steel ball that had fallen farther. Try Activity 5-6 again if you had problems answering this question.

5-4. Crater B was formed by the greater mass. You should review your data for Activity 5-5 if you had difficulty answering this question.

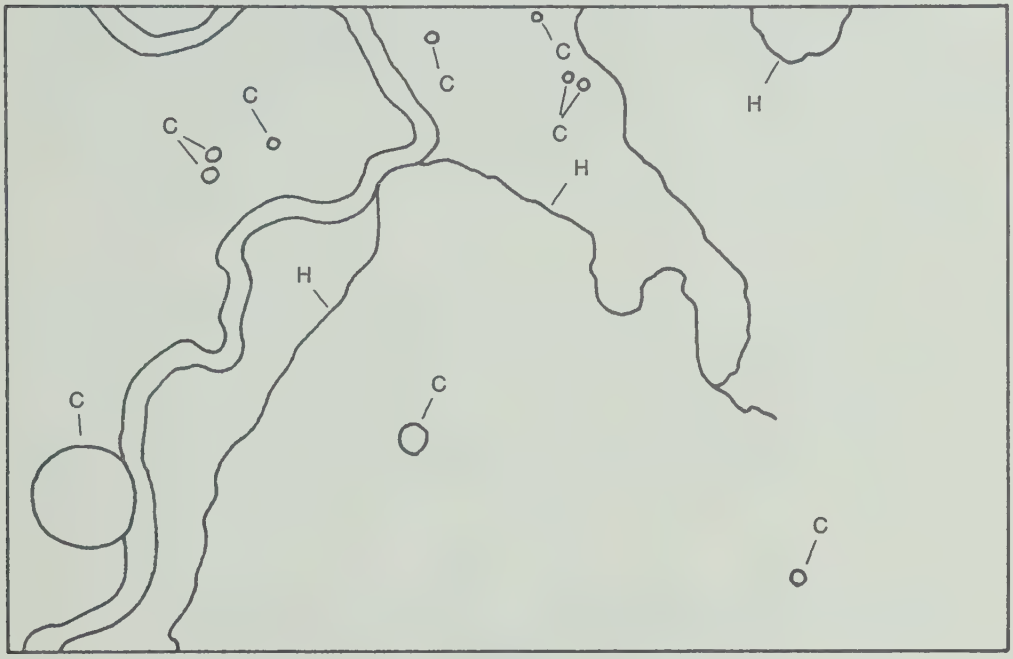
5-5. Your answer should have included such characteristics as a bowl-shaped crater with its floor a little below the level of the surrounding

land, a round shape with a raised rim, and ejecta scattered on the surrounding landscape.

5-6. a. You should have identified crater B as being the older crater.

b. You should have noticed that crater A seems to cut into crater B at the nearest point and that crater B contains debris that was thrown out of crater A when it was formed. Also, the edges of crater A are sharper than those of crater B.

5-7. The diagram shows the relative positions of the hills and craters.



5-8. Your answer should have included the idea that falling objects ejected some of the lighter material from below the surface of the moon and splashed it across the darker material of the surface. You may also have mentioned that the surface may have been darkened by radiation from the sun. Review Activities 5-12 through 5-14 in your text if you had difficulty with this question.

SELF-EVALUATION 6

6-1. a. Crater B was formed by an object that caused both the surface and the object to become molten when it hit.

b. Your answer should have included the idea that the central peak of crater B was formed by an inflow of material during the later part of the impact. Review text pages 109–112 if you are unsure of your answer.

6-2. You should have mentioned such things as a bowl shape (impact) or a cone shape (volcanic) crater, the floor of the crater below the level of the surrounding ground (impact) or above the level of the surroundings (volcanic), and evidence of a lava flow (volcanic) or widely scattered ejecta (impact).

6-3. One possible cause might be an underground flow of magma that would have lifted the surface rock. A large flow might have caused a large enough bulge to produce a mountain range. Review text pages 115–117.

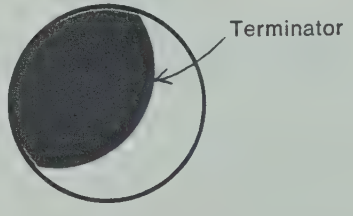
6-4. Features on the moon cannot be changed by weathering as we know it here on the earth. There is no atmosphere, and therefore no "weather" on the moon. But the features can be changed by micrometeorites hitting the surface, by moonquakes and settling, and possibly by volcanic activity on the moon.

SELF-EVALUATION 7

7-1. a. The observer would see the moon as in diagram B. If you had difficulty visualizing the situation, you may want to set up a model of the earth-moon-sun system as you did for Activity 7-3 and see what it looks like.

b. Yes. The sun would be rather low on the horizon in one direction, and the earth somewhat higher in the sky in the opposite direction.

7-2. The diagram shows the position of the terminator. Review text page 125 if you forgot what the terminator was.



7-3. Your answer should have included the idea that the moon rotates on its axis in the same amount of time that it takes to make one revolution around the earth. As a result the same side of the moon always faces the earth and we can never see the far side. See page 127 in the text.

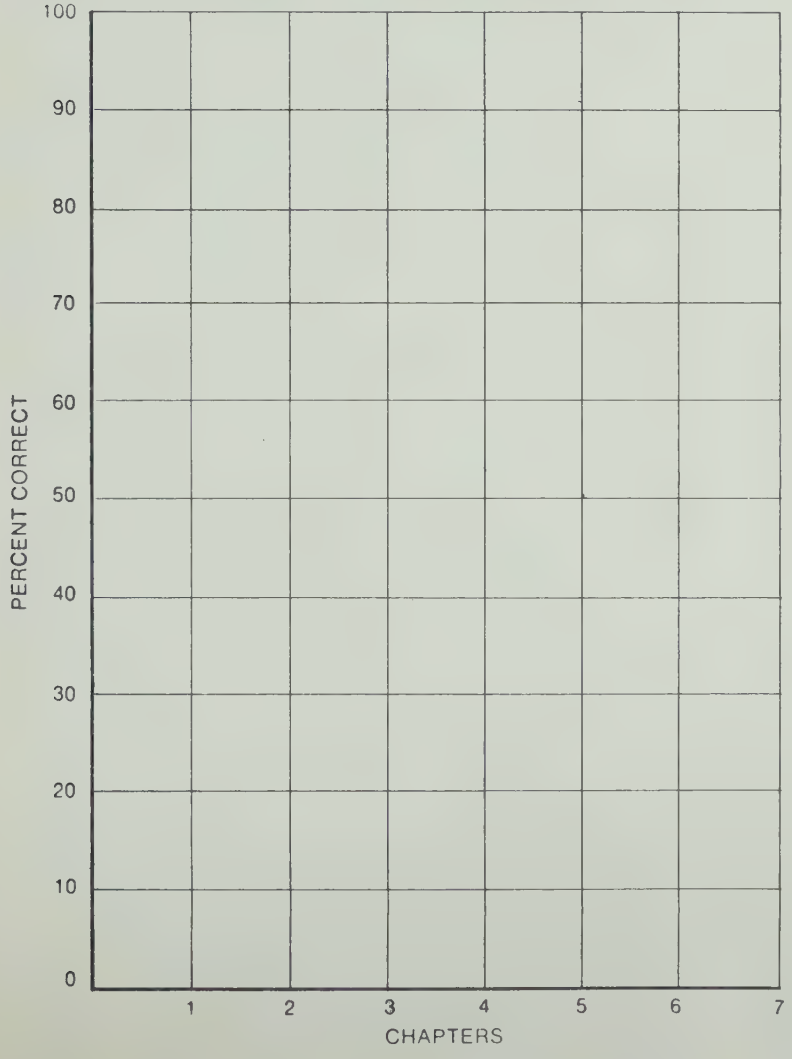
7-4. 365.25 days. Of course, your answer could have been 1 year, or 8766 hours, or 525 960 minutes.

My Progress

Keep track of your progress in the course by plotting the percent correct for each Self-Evaluation as you complete it.

$$\text{Percent correct} = \frac{\text{Number correct}}{\text{Number of questions}} \times 100$$

To find how you are doing, draw lines connecting these points. After you've tested yourself on all chapters, you may want to draw a best-fit line. But in the meantime, unless you always get the same percent correct, your graph will look like a series of mountain peaks.



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